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THE STATUS OF EVIDENCE BEARING ON OPTIMUM SIZE FOR FIRST CAPTURE OF ICNAF SUBAREA 4 COD

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Abstract

A 10-year study of ICNAF subarea 4 cod has demonstrated that sizes, abundance and landings are controlled by the environment and by fishing. Special emphasis has been given to the cod fisheries of subdivisions 4T and 4X, but the results are believed to be applicable to the whole subarea, west of the Laurentian Channel.

Landings depend in part on the abundance of year-classes. Year-class strength is related to water temperatures during early development. Good year-classes have been produced in relatively cold years.

The growth rate of cod is of considerable importance as a limiting factor on landings. An increase in cod growth in 1955 and 1956 in subdivision 4T was coincident with a herring disease, Ichthyosporidium hoferi, and with a reduced density of cod. The change resulted in record landings of cod.

Landings have been positively correlated with landed price of cod. Adverse economic conditions have reduced landed price and landings.

Construction of models of the fisheries shows that landings can be expected to decrease when size at first capture is too small, or when fishing intensity is too high. Optimum size for first capture is estimated to be considerably higher than the 50% retention length of a 4½ inch mesh. Optimum fishing intensity, for high catch-per-unit-effort consistent with maximum landings, is calculated to be lower than that of the 1950's, at comparable sizes for first capture.

The large increases in sizes, abundance, and landings of subarea 4 cod at the end of World War II, following a period of reduced otter trawling, are consistent with the changes expected from the study of models.

It is contended that adoption of a 4½ inch mesh size for subarea 4 cod is only a first step in international management, and that as a second step a mesh size of 5½ to 6 inches is believed to be desirable and practical. Equivalent restriction of hook and line fishing may also be required.

Methods of measuring the effects of regulations require special emphasis in the research program.

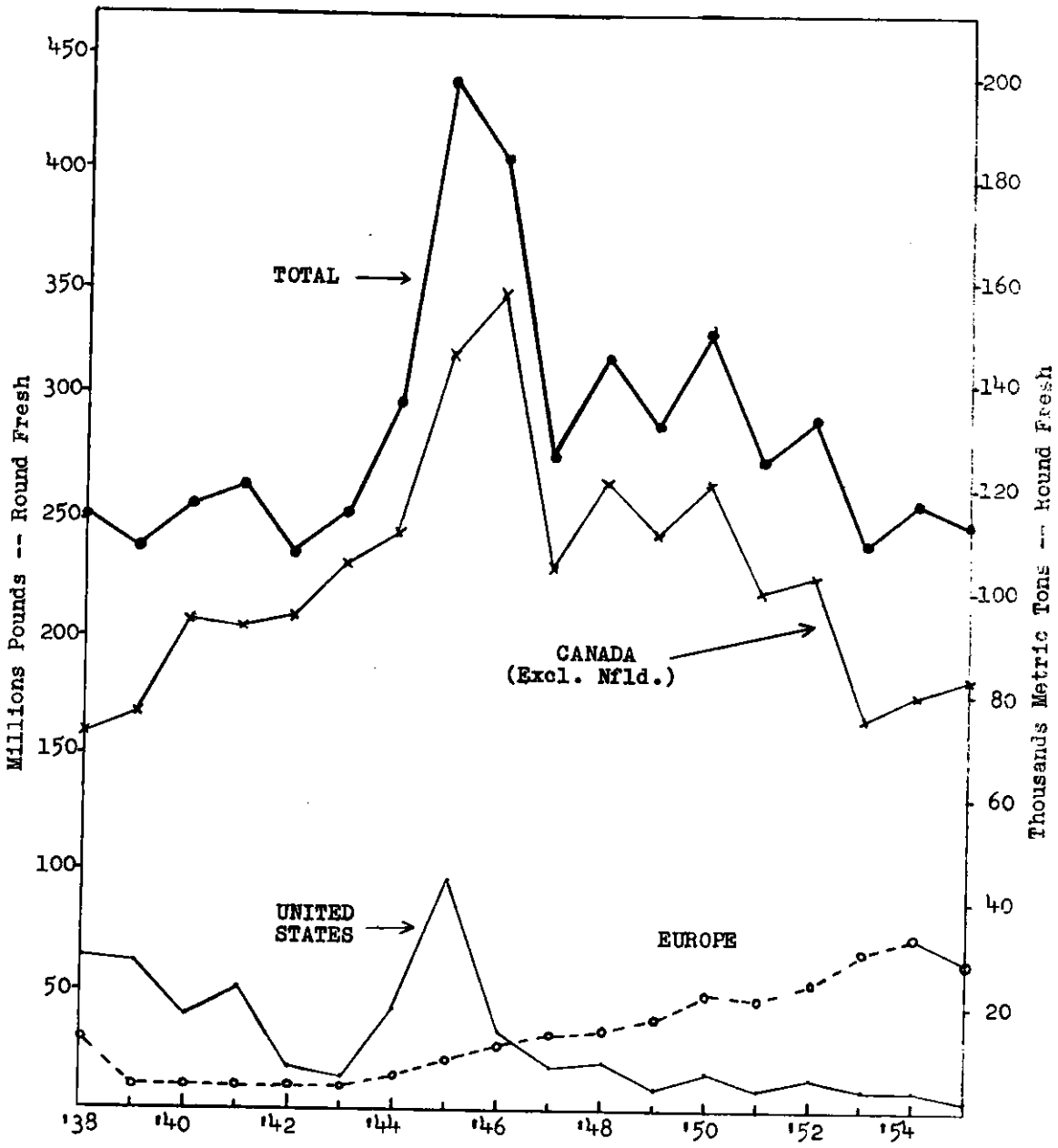

Figure 1. Cod landings for the years 1938 to 1955 from subarea 4 (excluding subdivision 4R) in Canada, Europe (France, Portugal, and Spain), United States. Combined landings are shown as total.

Introduction

In 1955 the International Commission for the Northwest Atlantic Fisheries recommended a 4½ inch mesh size for cod and haddock fishing in subarea 4. This mesh regulation was proposed to increase landings from these fisheries. Adoption of this mesh regulation will release large numbers of small, fast-growing fish at sizes which were previously caught and discarded at sea because they were unmarketable. It is expected that many of these fish will live and grow to augment the landings of marketable sizes.

This paper contends that adoption of a 4½ inch mesh is only a first step in making better use of the subarea 4 cod stocks. The status of evidence bearing on optimum size for first capture of two stocks of cod is considered. A discussion of various mesh and hook sizes indicates that a further increase in size at first capture of subarea 4 cod is a practical possibility. Finally, a number of research problems are proposed for action before the Commission takes additional steps in the management of subarea 4 cod.

Subarea 4 landings

Annual landings of cod from subarea 4 have varied widely. Landings for the period 1938 to 1955, as recorded in ICNAF Statistical Bulletins, are plotted in Figure 1. Cod from subdivision 4R have been excluded since they are part of the different cod stocks which live east of the Laurentian Channel in subarea 3 (Templeman, 1955). Canada, United States and three European countries, France, Portugal and Spain, have shared the catch in the proportions shown. The Canadian statistics are based on landings from subarea 4 in Canada, excluding Newfoundland. This is reasonable because most of the Newfoundland landings from subarea 4 were taken from subdivision 4R, and landings in other Canadian Atlantic provinces from subdivision 4R were negligible. Total United States landings from subarea 4 are shown. Here again, landings from subdivision 4R were very small. It has been necessary to estimate most of the European landings. Landings for 1954 and 1955 have been reported by subdivisions, and combined landings from all subareas are available for the whole period. On the basis of percentages landed from subarea 4 (excluding 4R) in 1954 and 1955, landings for the years 1938 to 1953 have been estimated to be 7% of the total landings. Landings by Latin countries from subarea 4 are known to have been small during war years. Total landings of cod from subarea 4 (excluding subdivision 4R) are recorded as the sum of these reported and estimated statistics.

These total landings are shown again, in relation to sizes landed and abundance indices, in Figure 2. Annual variation in sizes landed is indicated by the percentage of large cod (over 10 pounds, head-on, gutted weight) in United

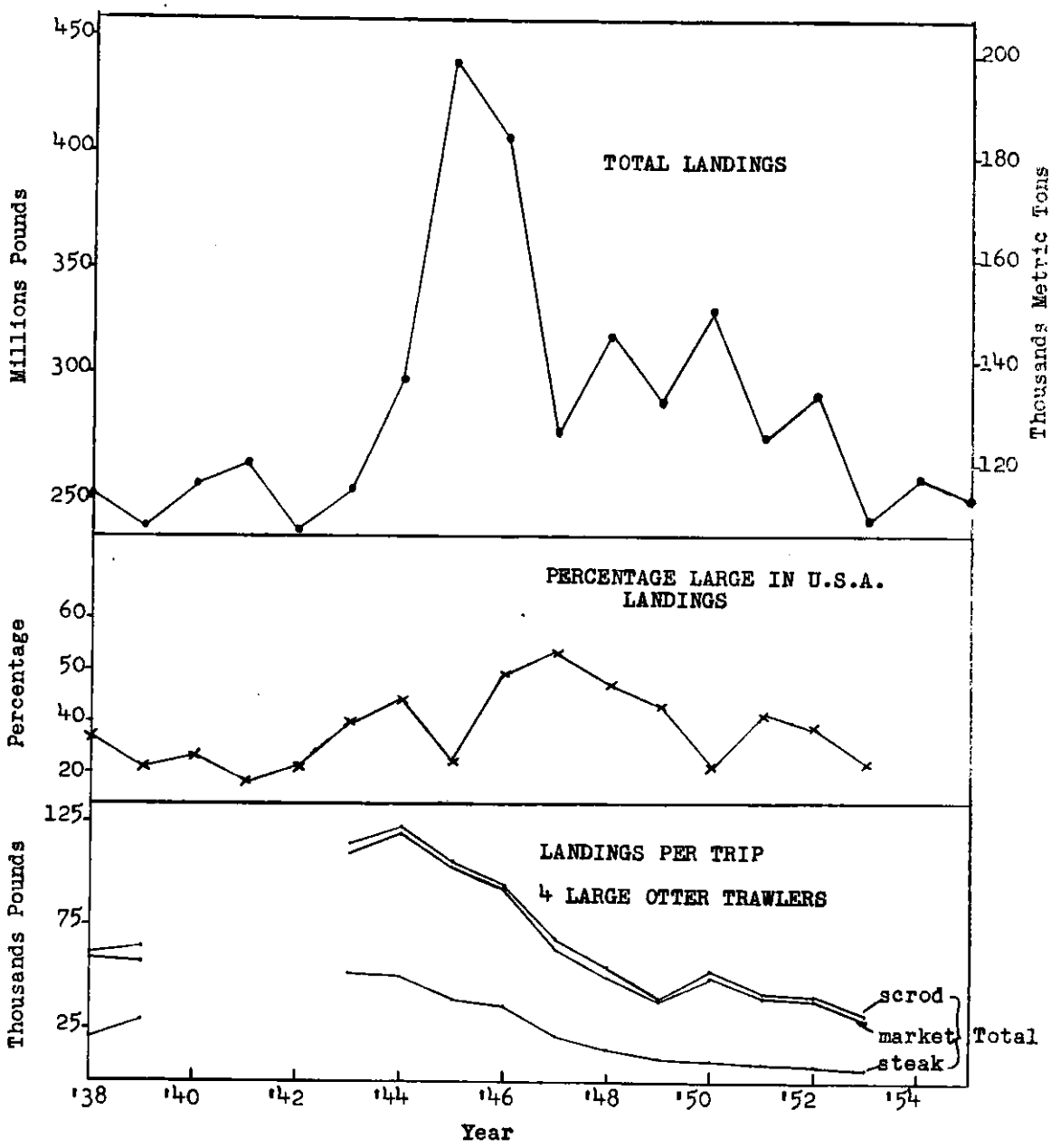

Figure 2. Total cod landings from subarea 4 (excluding subdivision 4R); percentage of large cod in United States landings from this area; and landings per weekly trip of scrod, market, and steak cod by Canadian trawlers.

States landings from subarea 4. Individual trip reports for Canadian otter trawlers (151 to 500 gross tons) provided indices of abundance for steak (over 10 pounds, head-on, gutted weight), market (2.5 to 10 pounds) and scrod (1.5 to 2.5 pounds) cod.

During war years total fishing effort decreased sharply and this was particularly true for otter trawlers. Most of the European fishing in the southern part of the Convention Area was by Portuguese dory schooners, and little of this was carried out in subarea 4. United States otter trawlers fished less in subarea 4, especially in 1942 and 1943. The five Canadian otter trawlers which were in operation before the war were diverted from fishing during the early war years. Canadian otter trawling did not start to expand until 1945.

At the end of the war Canadian line fishermen landed more cod per year from subarea 4 than all countries combined landed in 1938 or 1955. The abundance of cod, as measured by average landings per weekly trip of otter trawlers, increased to a peak in 1944. Average landings per trip of steak cod were higher then than the average landings per trip of all size categories of cod in the years 1951 to 1953. The proportion of large cod in United States cod landings from subarea 4 increased during war years and reached about 50% by weight during the years 1946 to 1948.

To sum up, high total landings, high individual catches, and large sizes of cod were taken from subarea 4 at the end of World War II.

A number of explanations for this peak in the cod fishery have been considered:

(1) Gordon (1955) has shown that Canadian landings of cod have been correlated with economic factors. During depression years, in the 1930's, landed price and landings were low for cod. During war years landed price and landings were high. He pointed out that the economic relationship was tentative, and that other cyclical changes were observed which could not be attributed to fluctuations in economic factors.

(2) McLellan and Lausier (1956) have shown that the ratio of haddock to cod landings for subarea 4 has fluctuated annually in a manner similar to changes in water temperature on the Scotian Shelf. The relationship is consistent with the known preference of cod for colder water than that favoured by haddock.

(3) Changes in distribution, recruitment, and growth of cod may have resulted in the peak landings of cod. Large variations in all three factors have been observed in other areas with resultant effects on landings.

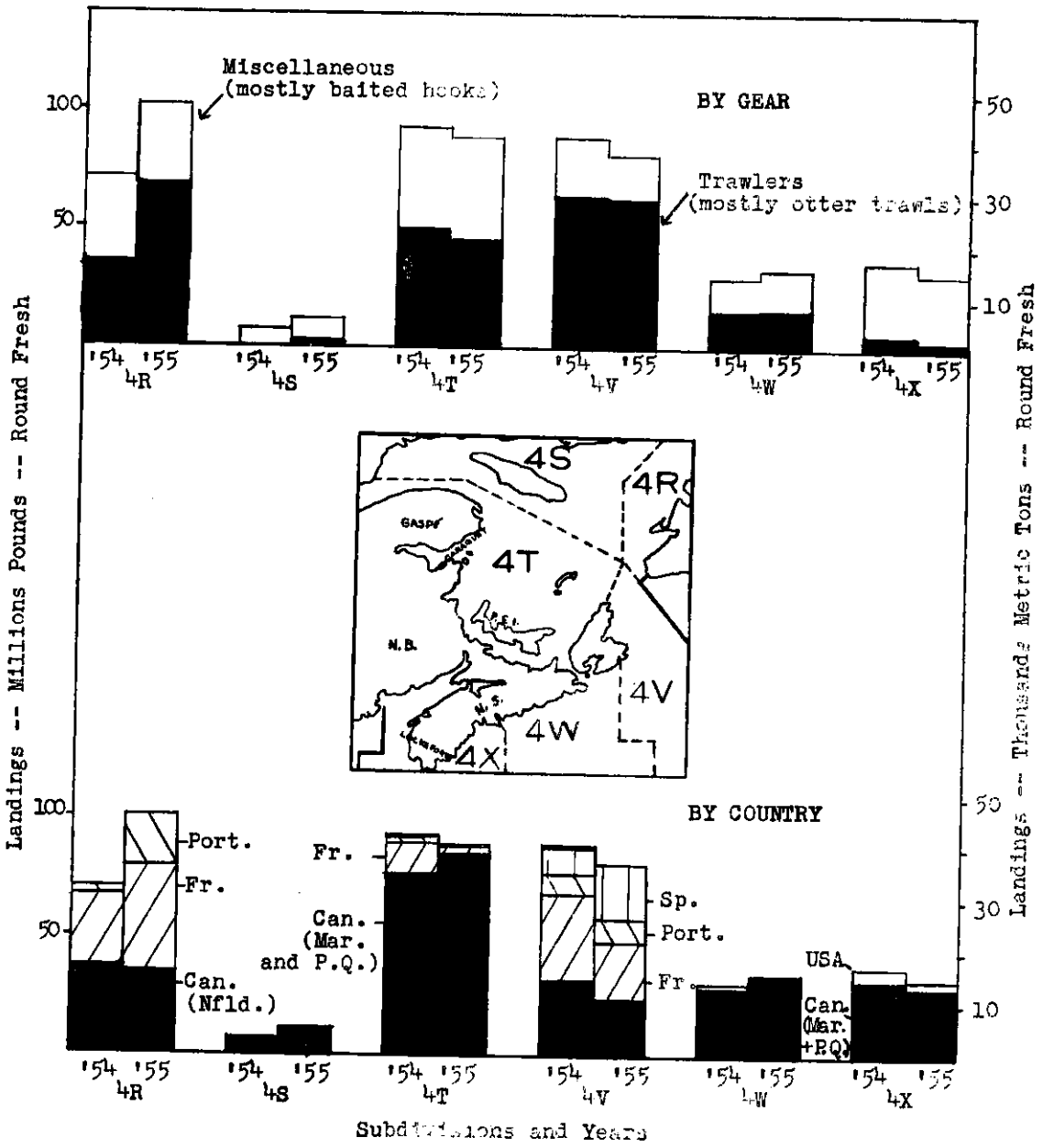

Figure 3. Cod landings for the years 1954 and 1955 from the subdivisions of subarea 4 by gear, and by country, (Canada, France, Portugal, Spain, United States).

(4) The situation resembles that of some of the groundfish of the North Sea immediately following each World War (Graham, 1956) when landings, abundance and sizes of fish all increased following a period of greatly reduced fishing effort. Fishing effort did not change as drastically in subarea 4 during war years as in the North Sea. Otter trawling declined to a very low level in the middle of the war, the amount of line fishing gear, as reported in Fisheries Statistics of Canada, decreased, but remained large enough in subarea 4 to maintain landings at a level equal to that of total landings in 1938 or 1955 when international fishing with all types of gear was much more intensive.

(5) The high relative importance of line fishing during war years meant that the size of cod at first capture was larger then than during the post-war period. By 1954 over half the cod catch was taken by small-meshed otter trawls, and the size at first capture was considerably smaller than it was during war years when otter trawling was of little importance in the fishery.

The subarea 4 cod stocks were not studied biologically during war years, and the relative importance of these various factors is not known. However, subsequent investigations of their effects on the quantities and sizes of cod landed from subarea 4 have provided background for interpretation of earlier fluctuations, and for prediction and management of the cod fishery. Some of the results of these cod studies are considered in this paper.

Landings by subdivisions

The subarea 4 cod-fishing grounds are divided by tortuous land masses, and by deep-water gulfs and gullies, into a number of distinct regions. South of Nova Scotia inshore grounds are separated from offshore grounds, and offshore grounds are divided into a number of banks. In the Gulf of St. Lawrence there is an extensive shoal-water fishing area extending from Cape Breton Island to the Gaspé Peninsula. Extensive studies of vertebral counts (McKenzie and Smith, 1955) and tagging (McKenzie, 1956) have shown that these various fishing grounds support a number of cod populations. Separate inshore cod populations are found off western, central, and eastern Nova Scotia. On offshore Nova Scotia banks cod populations are similarly divided. Gulf of St. Lawrence cod are distinct from these Nova Scotian cod populations.

The statistical subdivisions of subarea 4 conveniently separate the major cod stocks along the southern Canadian mainland, and further discussion of cod populations will use these terms of reference.

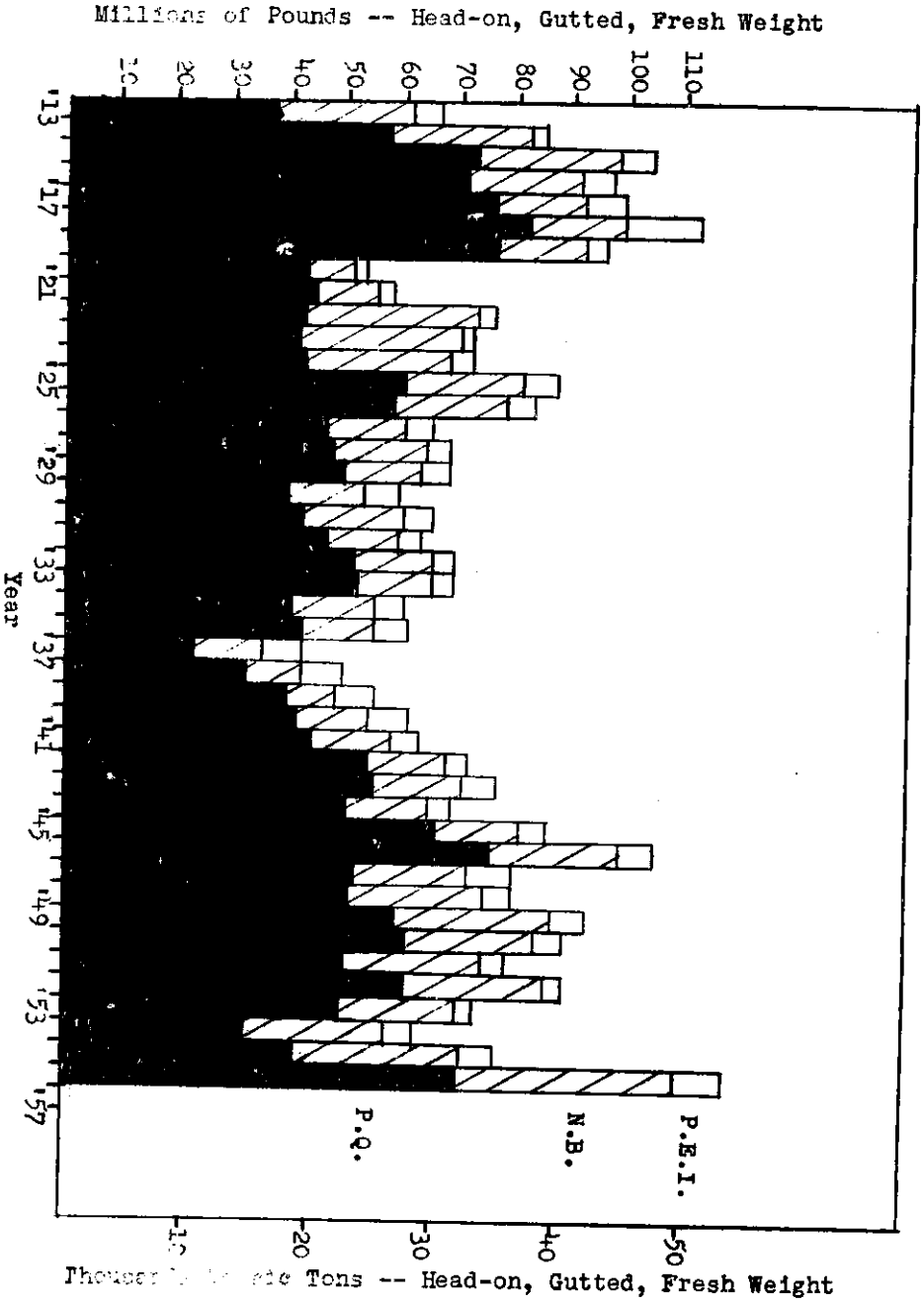

Figure 4. Cod landings for the years 1913 to 1956 in the Canadian Provinces of Quebec, New Brunswick and Prince Edward Island from subdivision 4T.

The quantities of cod landed by gear and by country from the various subdivisions of subarea 4 in 1954 and 1955 are shown in Figure 3. Cod has been an important commercial species in all subdivisions. The smallest landings were taken from subdivision 4S and the largest landings from subdivision 4T.

Otter trawling has become increasingly important during the post-war period. More than half the landings were taken by otter trawlers in 1954, and additional small quantities were landed by similar gear, Spanish pair trawlers. The remainder were taken by miscellaneous fishing, mainly by inshore hook and line gear (longlines and handlines with baited hooks). Dory schooners, jigs, and a few trap nets contributed small percentages of the miscellaneous landings. Much of the line fishing, which was of primary importance during war years, has been replaced by otter trawling.

Most of the United States cod landings were taken by otter trawlers from subdivision 4X. Trawlers from France, Portugal and Spain fished during spring months in deep water along the Laurentian Channel, and took large catches from subdivisions 4R, 4T and 4V.

Canadian fishing accounted for a large share of the cod landings from all subdivisions. In subdivision 4T there has been a rapid post-war conversion from line fishing craft to draggers (small otter trawlers of 26 to 50 gross tons). However, inshore line fishing has continued to be important in subdivision 4T, particularly along the Gaspé coast of Quebec. In subdivision 4X cod have been mainly caught on rough bottom with baited hooks. Adoption of longlining with power haulers has increased the efficiency of line fishing there since the end of World War II.

Biological investigations of the cod fisheries off Caraquet, N. B., in subdivision 4T, and off Lockeport, N. S., in subdivision 4X, have provided detailed information on geographic and annual variations in the cod landings from subarea 4. In both cases, studies have been carried out from the principal landing port in a subdivision where Canadian fishing accounted for most of the total catch. Since about half the cod taken west of the Laurentian Channel in subarea 4 have come from these two subdivisions, the results undoubtedly apply to the whole subarea. The biological characteristics of cod from subdivisions 4V and 4W are intermediate between those of 4T and 4X. The following two sections will deal with some of the results of the studies of subdivisions 4T and 4X cod.

Subdivision 4T cod

Landings. Most of the cod caught in subdivision 4T have been landed in Canada, and most of these Canadian landings have

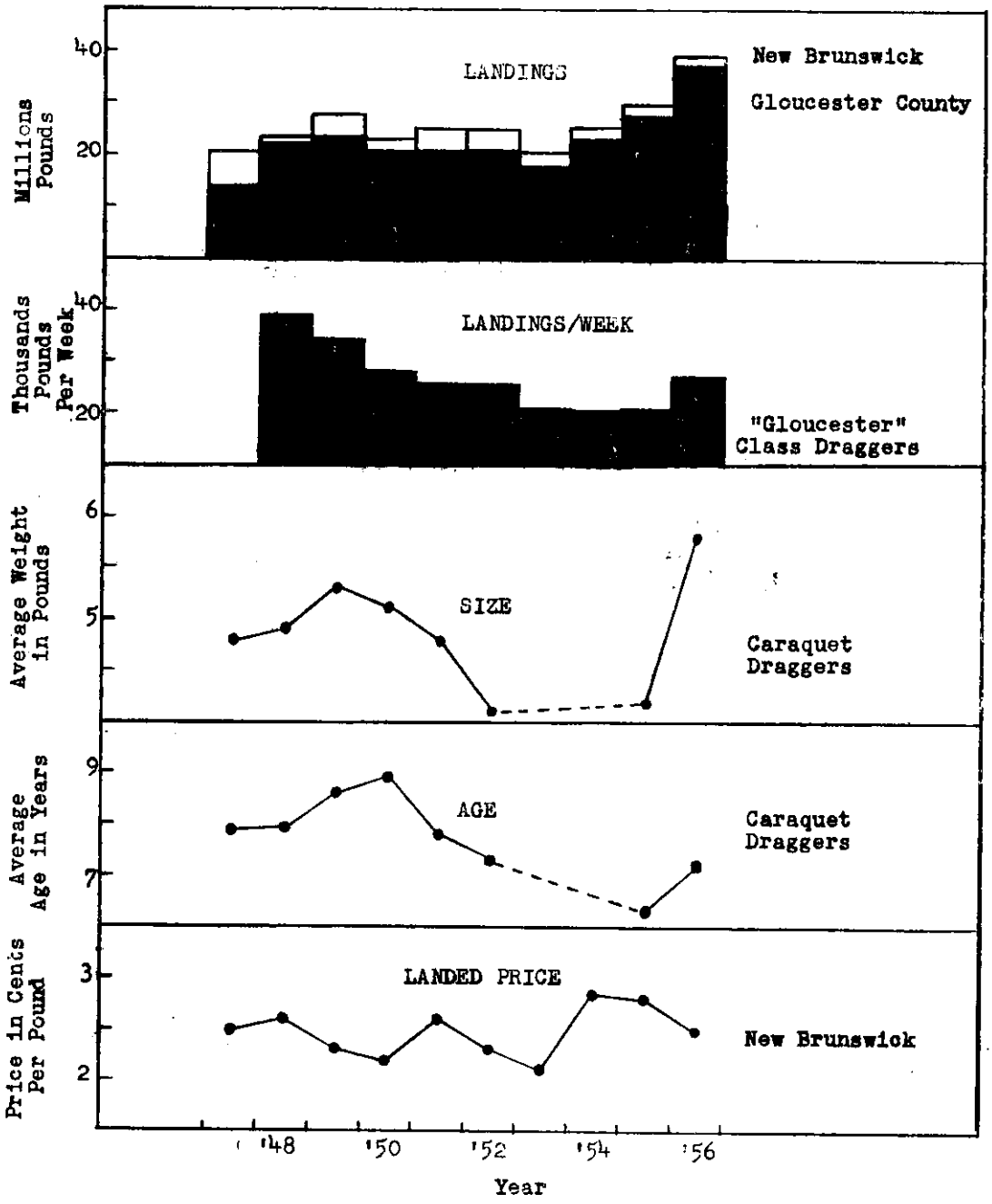

Figure 5. Annual variation in landings, landings per "Gloucester" dragger per week, sizes, ages, and landed price of cod in northern New Brunswick, Canada, during the years 1947 to 1956.

been in the provinces of Quebec, New Brunswick and Prince Edward Island. Landings from other subdivisions in these provinces have been small. Statistics of cod landings in Quebec, New Brunswick and Prince Edward Island for the years 1913 to 1956 are shown in Figure 4. The annual variations are believed to be of the same order as annual variations in total landings from subdivision 4T.

Annual landings were lowest in 1937 and highest in 1918, 1946 and 1956. Landings were relatively low during depression years, and relatively high during the latter part of each World War. Shorter-term variations in landings were also large. Landings in 1956 were almost double those of 1954.

Landings in New Brunswick during the past 10 years (1947 to 1956) are shown in Figure 5. Most of the New Brunswick cod have been landed along the northeast shore of the province, in Gloucester County. Landings there increased in 1946, before draggers were introduced to the Gloucester County fishery in 1947 (Figure 4). By 1954 the line fishery took only about 20% of the New Brunswick landings, and draggers landed the other 80%. During this conversion from line fishing to dragging, total cod landings in Gloucester County remained fairly steady at about 20 million pounds per year until 1954. Landings then increased to 39 million pounds in 1956. During the expansion of the dragger fleet, landings per week of fishing by "Gloucester" class draggers decreased from 39 to 21 thousand pounds (Figure 5). In 1956 this abundance index increased again to 27 thousand pounds.

Sizes and ages. The average sizes and ages of cod landed by Caraquet draggers varied a great deal during this 10-year period (Figure 5). During the years 1947 to 1951 the cod were relatively large (average 5 pounds) and old (average 8 years). Average size and age decreased in 1952, and according to Marcotte (1955) decreased substantially from 1952 to 1953. Our sampling was incomplete in 1953 and 1954. In 1955 cod were similar in size to those landed in 1952, but they were faster-growing cod, averaging about one year younger. In 1956 growth continued to be rapid. Average size of dragger cod was the highest in 10 years, but the average age was lower than that observed in the years 1947 to 1952.

The sizes and ages of cod landed by draggers at Caraquet are shown in greater detail in Figure 6. During the years 1948 to 1950 many age groups were represented in the landings, and average size and age increased slightly as the dominant 1941 year-class passed through the fishery. In 1951 younger age groups became more important, and the proportion of scrod cod increased. In 1952 and 1955 the dominant age group was 5-year-old fish. In 1956 average age increased by a year, and the dominant size group was 5-pound cod.

Sizes discarded. In 1956 the regular sampling for length composition of commercial landings of cod at Caraquet was supplemented by sampling of the sizes and relative numbers of

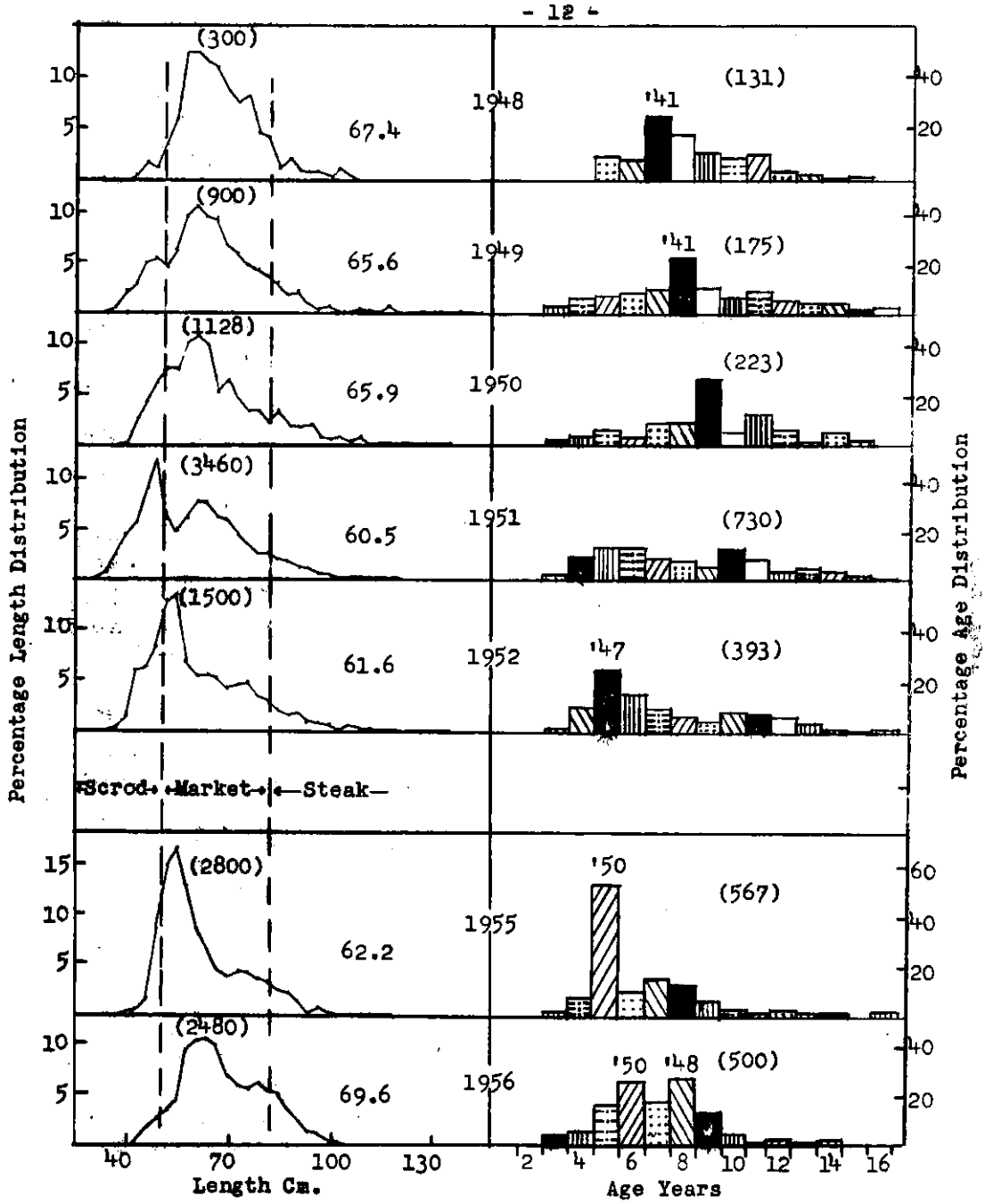

Figure 6. Percentage length and age distribution of cod landed at Caraquet, N. B., from subdivision 4T during the months of August to October, 1948 to 1952 and 1955 to 1956. Average lengths are noted, and numbers of fish measured and aged are recorded in brackets.

cod discarded at sea from commercial draggers. Five trips were made on draggers (55-75 feet) to Bonaventure Island and Orphan grounds (30-125 fathoms). Two trips were made on smaller draggers (45-49 feet) to Chaleur Bay and Shippegan Gully grounds (20-45 fathoms). In all cases the mesh size was 3½ inches between knot centres, new, 100/3 strand manila, or about 2 7/8 inches, inside, stretched, used, wet measure. The results are summarized in Figure 7. The percentages of cod discarded were 18 by number and 4 by weight for the deep-water, large-fish, large-dragger trips, and 55 by number and 14 by weight for the shoal-water, small-fish, small-dragger trips. Most of these cod were dead or beyond recovery when rejected at sea as unmarketable fish.

Tagging. Cod were tagged in the Caraquet area in 1955 to provide information on movements and mortalities. Yellow plastic Petersen disk tags were attached with stainless steel wire to the backs of 2,650 cod, and Lea hydrostatic tags were similarly attached to 1,208 cod.

The locations of recaptures to May, 1956, of Miscou and Shippegan Gully taggings are shown in Figure 8. During the "summer" season of June to November, 1955, most recaptures were taken by Canadian draggers close to the area of tagging. Some of the cod moved in a northeasterly direction during this season. The Gulf fishery stops because of bad weather and ice conditions during the "winter" season of December to May. But during this "winter" period the tagged cod continued to be taken along the Laurentian Channel off eastern Nova Scotia. Most of these recaptures were taken by large European trawlers operating in deep water, over 100 fathoms. In the "summer" of 1956 most recaptures were again taken by Canadian draggers in the northern part of subdivision 4T. It is apparent that these cod support two major fisheries, one in the western Gulf of St. Lawrence during summer, the other in the western Cabot Strait area in winter.

The distribution of tag recoveries, by season and by subdivision, is summarized below. About 20% of the cod tagged during the summer of 1955 had been recaptured and reported by the end of December, 1956.

Subdivision	June-December 1955	January-May 1956	June-December 1956
4T	163	14	255
4V	2	50	1
Others	2	9	4

Factors affecting landings. Some of the causes of annual variations in landings of subdivision 4T cod are considered

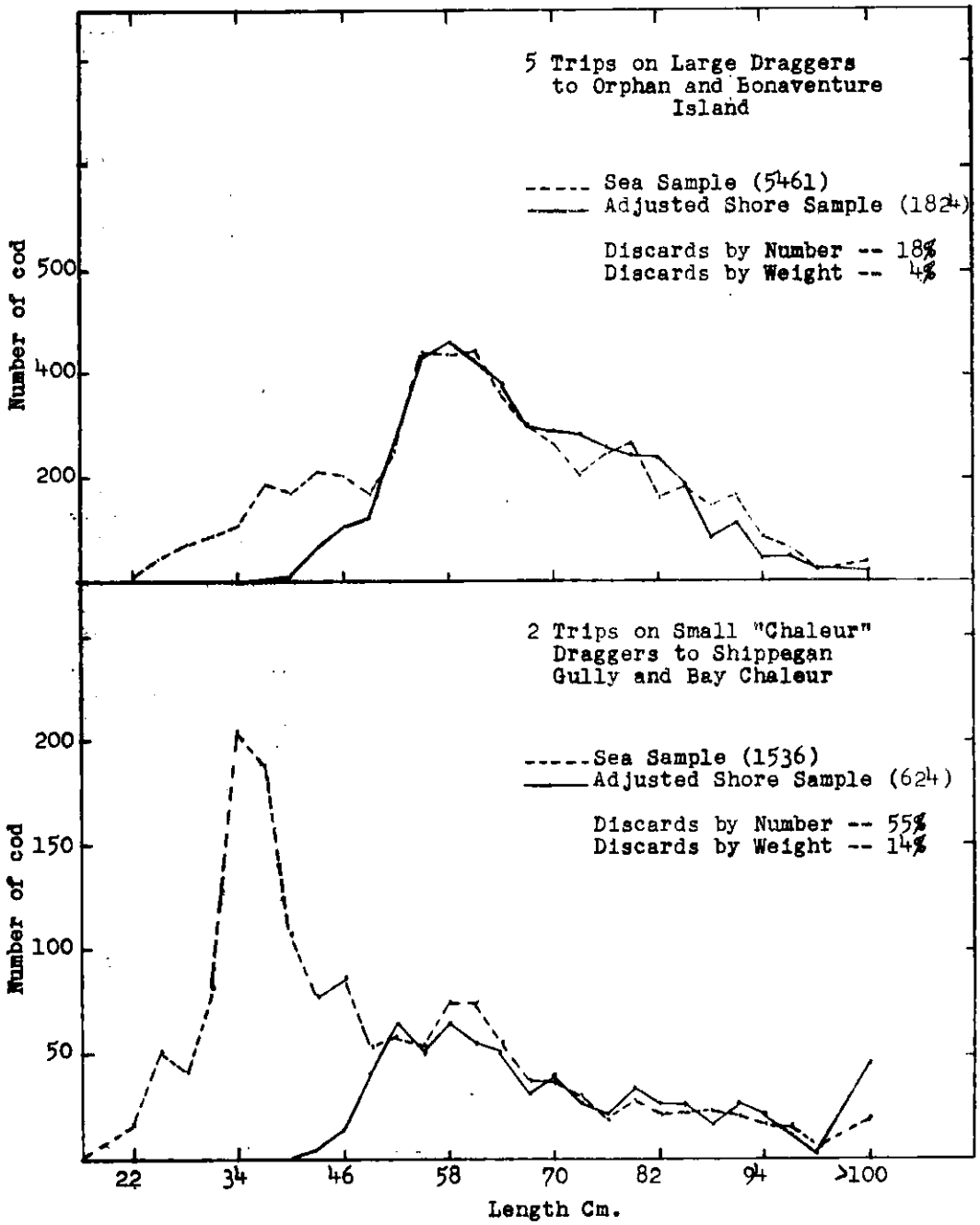

Figure 7. Percentage and size distribution of cod discarded at sea by draggers fishing from northern New Brunswick in subdivision 4T during 1956. Numbers of fish measured are recorded in brackets.

under environmental and fishing headings. The environmental factors are described under "recruitment" and "growth". Effects of fishing are considered under "landed price" and "models".

(a) Recruitment. At the northern limit of the cod range, in subarea 1, Hansen and Hermann (1953) have observed that the years with the highest temperatures coincide with the best year-classes in cod. Conversely, at the southern end of the cod range, in subarea 5, Martin (1953) has observed that high yields of cod were produced when surface temperatures were below the long-term average, and low yields of cod have been observed when average temperatures during the first year of development were above normal.

Mean surface water temperatures in subdivision 4T, at Entry Island in the Magdalen Islands of Quebec, are compared with dominant year-classes of cod in Table I. Maximum spawning occurred in the latter part of June in 1955, but some spawning was observed as late as August. Mean monthly temperatures for the period May to October (Lauzier 1953) were averaged to obtain an index of the annual variation in mean temperature during development. It may be noted that those of the four dominant year-classes shown in Figure 6 were produced in years when water temperatures were below the 20-year mean. Analysis other than that described in Figure 6 shows that a good year-class was also produced in subdivision 4T during the cold water year 1939. The 1941 year-class, which was dominant in landings for four years, was produced in the coldest year

Table I. Mean surface temperature in degrees Centigrade during May to October, 1937 to 1956, at Entry Island, P.Q.

Year	Temp.	Temp. below normal	Dominant year-class	Year	Temp.	Temp below normal	Dominant year-class
1937	12.2			1947	12.3		X
1938	12.1			1948	11.2	X	X
1939	11.3	X	X	1949	12.2		
1940	11.3	X		1950	11.8	X	X
1941	10.5	X	X	1951	12.8		
1942	12.9			1952	12.6		
1943	11.4	X		1953	12.0		
1944	11.9			1954	11.4	X	
1945	12.1			1955	11.9		
1946	11.9			1956	11.7		
				Mean	11.9		

A general warming of subarea 4 waters was observed during the years 1940 to 1953 (Lauzier, 1954). Some indication of this trend is apparent in the table. There is no suggestion of a reduction in recruitment as temperatures increased. There are so many year-classes involved in the landings of any one

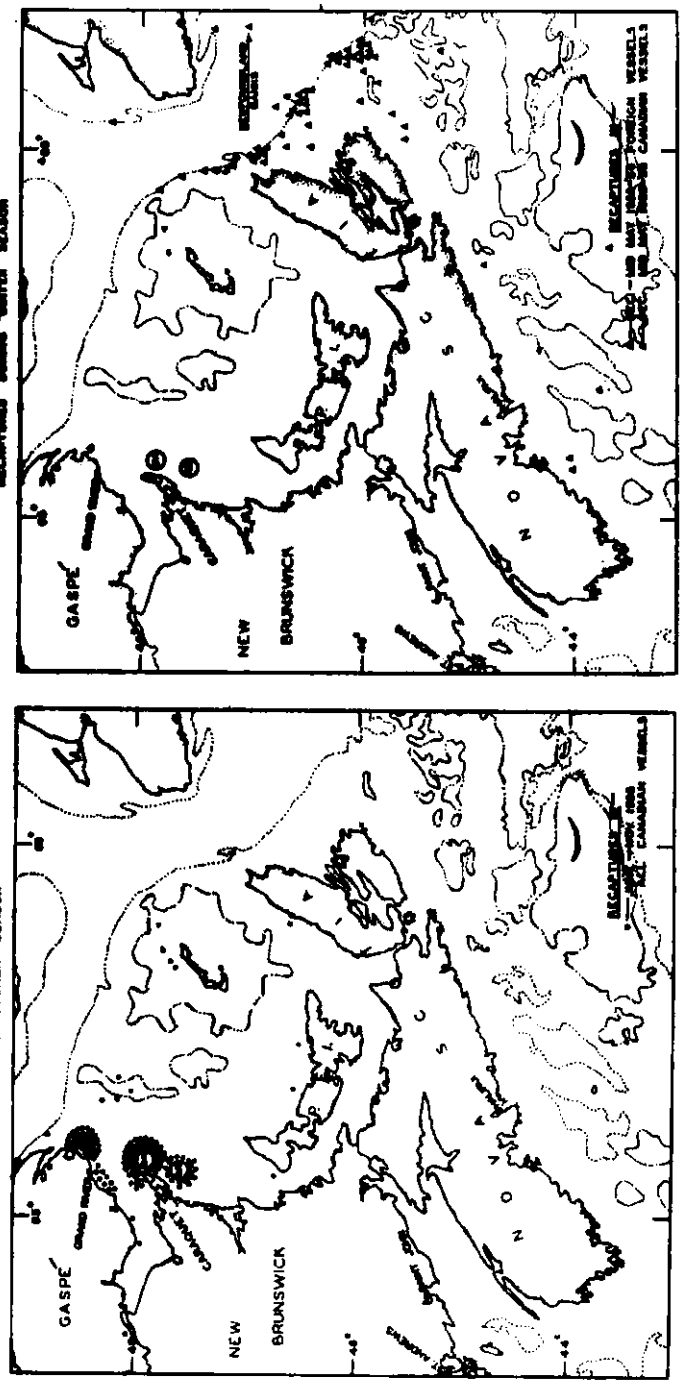

Figure 8. Recaptures of 1799 cod tagged off Miscou Island and 1020 tagged off Shippegan Island during 1956, by season.

year (Figure 6) that landings do not appear to be greatly affected by fluctuations in year-class strength. It should be noted, however, that the good year-classes, produced in the relatively cold years 1948 and 1950 were dominant in the peak landings of 1956.

(b) Growth. The growth rate of subdivision 4T cod is of primary interest in the study of effects of environmental factors and fishing on landings. We have already noted that growth was more rapid in 1955 and 1956 than during the years 1948 to 1952. The causes of this annual variation in growth and the effects on landings warrant examination.

Two Bertalanffy growth curves, together with observed growth points for Caraquet cod, are shown in Figure 9. The lower curve represents the average growth during the period 1948 to 1952. The upper curve describes the faster growth observed in 1956. Growth in 1955 conformed with that shown for 1956, but special samples of small cod were not taken. The increased growth rate in 1956 was particularly apparent in the cod. Eight-year-old cod increased from about 5 to 8 pounds fresh, head-on, gutted weight.

Examination of 332 gonads in late spawning condition showed that the size at which 50% of the cod matured was about 53 centimetres for males and about 59 centimetres for females. Growth rate decreased continually, but the decrease is particularly apparent beyond maturity.

Five hundred and fifty-one cod stomachs were examined in 1956. Crustaceans predominated in small cod, up to 60 centimetres, and fish was the principal food of larger cod. Decapods, euphausiids and mysids were the major crustacean groups. Herring contributed 50% by volume of the fish diet. Flounders, cod, and capelin were the other important fish found in these cod.

The increased growth rate of cod appeared to result from increased availability of moribund herring. A heavy mortality of herring was observed in subdivision 4T in the years 1954 to 1956. It was caused by a fungus, Ichthyosporidium hoferi (Leim, 1955). During mesh selection studies in 1954, large numbers of dead herring were observed in the net, and it was noted that cod were frequently gorged with decaying herring.

The density of cod, as measured by catch per week of fishing by "Gloucester" class draggers, decreased from 1948 to 1953, as the amount of fishing on this stock by Canadian and European otter trawlers increased. The reduced density of cod in subdivision 4T may have had an additive effect in increasing the growth rate.

The increased growth and increasing average size was associated with increasing landings in the years 1955 and 1956. Landings did not increase in numbers in 1956, but the larger

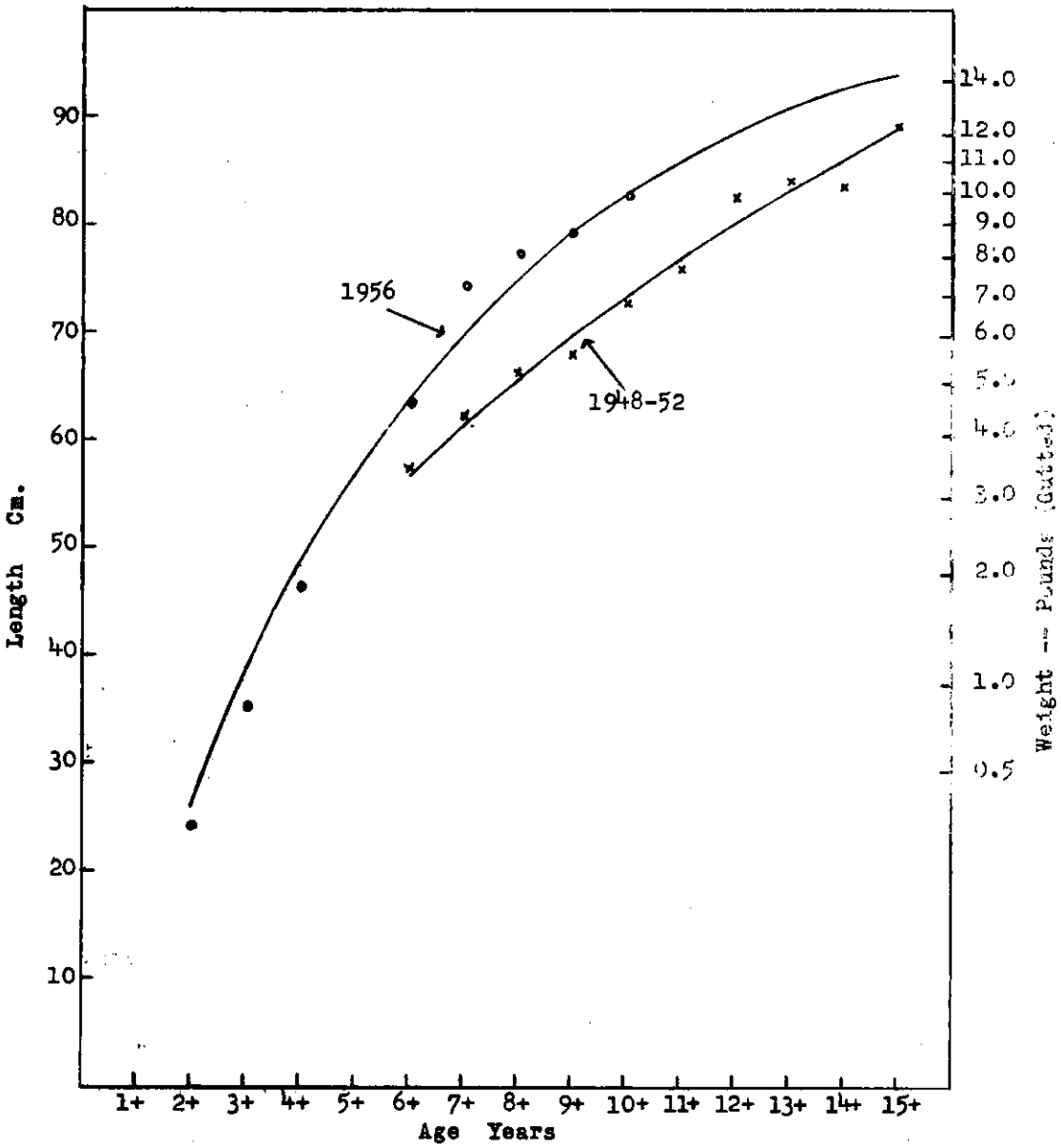

Figure 9. Growth in length of cod caught in the northern part of subdivision 4T by Caraquet draggers during two periods, 1948-52 and 1956. Observed average lengths and Bertalanffy growth curves are shown for the August to October season. An equivalent weight scale has been added.

sizes of fast-growing cod brought about a substantial increase in landings by weight. Landings in Quebec, New Brunswick, and Prince Edward Island totalled 118 million pounds, gutted weight, the largest landings on record.

(c) Landed price. In order to follow up Gordon's contention that economic factors contribute to catch fluctuations in cod, average price per pound to New Brunswick fishermen is plotted in relation to landings in Figure 5. Price fluctuations did not appear to have a pronounced effect on post-war landings. Landings and price were both relatively low in 1953, but the peak landings in 1956 were associated with a post-war average price per pound to fishermen.

Landings were low during the early post-war depression in 1921, and during the major depression of the 1930's. Landings and prices were relatively high during the latter years of each World War, during the 1920's and following World War II.

Fishing effort and landings may be reduced during depression years. However, during years when fish prices are relatively high factors other than landed price appear to be responsible for large fluctuations in landings.

(d) Models. Over and above the effects of recruitment, growth and landed price on landings of cod from Subdivision 4T, we must consider the effects of fishing as it affects the balance on yield.

It is believed to be of advantage to conserve the stock of small cod at sizes where growth rate exceeds mortality from natural causes. The advantage is greatest when growth is rapid. Subdivision 4T cod increase in weight by more than 100% per year up to the smallest marketable size. As noted below, this is believed to be greater than rate of losses by natural mortality. It was on this basis that the Commission recommended a minimum mesh size to produce a larger size for first capture of subarea 4 cod. The advantages of mesh sizes greater than 4½ inches remain to be considered.

In order to consider the effects of fishing on landings, a series of models have been calculated (Figure 1). The important variables involved are size at first capture and fishing intensity. Relative yields of cod have been determined for two levels of natural mortality, two growth rates, four mesh sizes, and a series of fishing mortalities. Yield curves have been drawn for the four mesh sizes, and lines representing three levels of catch-per-unit-effort are shown for each model.

Yields were calculated on the basis of 10,000 fish, fully recruited to the fishery at 30 centimetres. As noted in Figure 7, full recruitment at such a small size was not the case in 1956. Further studies may show that calculations should be based on a much higher size at recruitment, for it is known that cod are differentially distributed by size, and that small cod are not as available to commercial fishermen as small haddock.

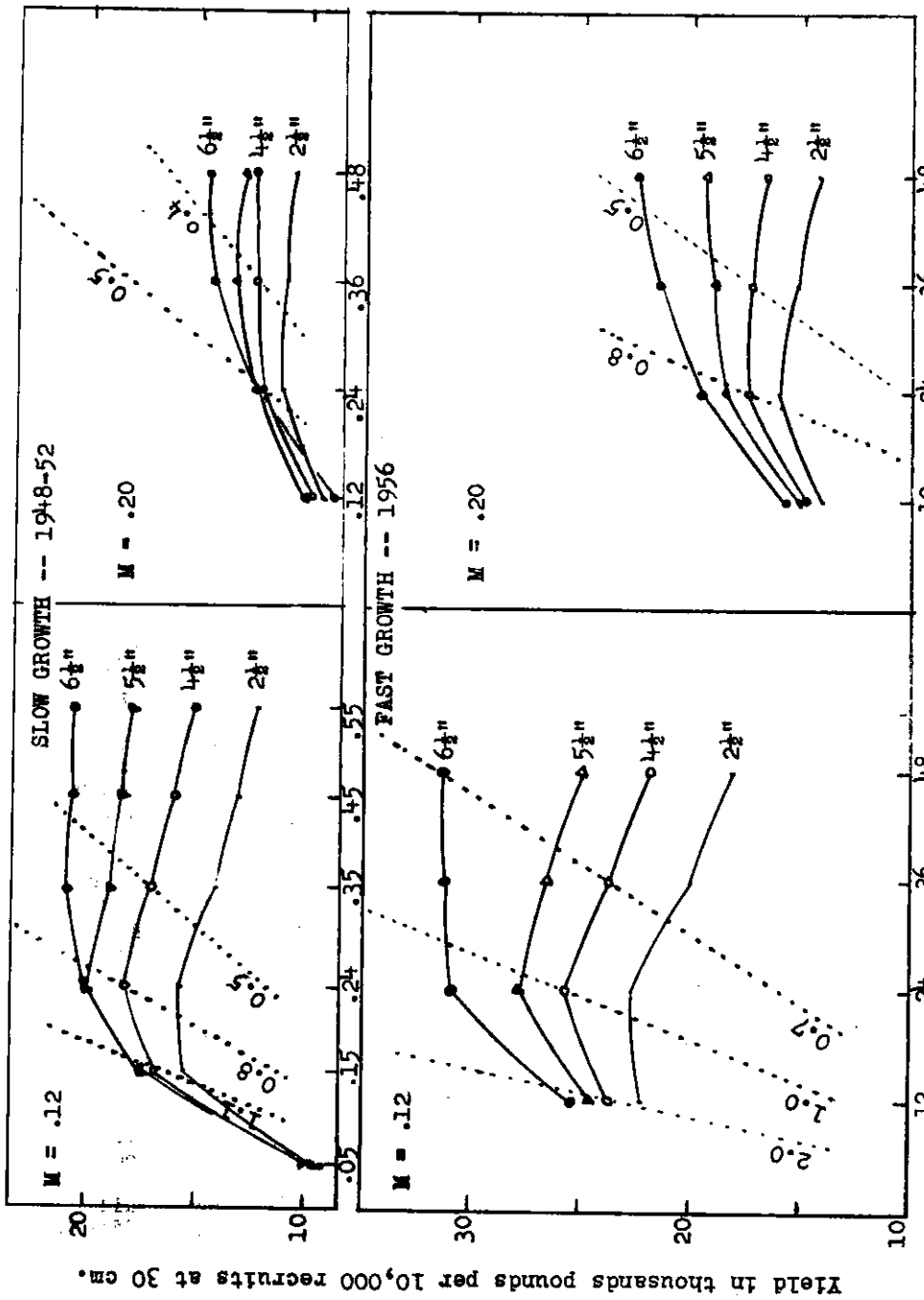

Figure 10. Model of subdivision 4T cod fishery, relating yield per 10,000 recruits at 30 centimetres to instantaneous fishing mortality rate (F) for gear selection equivalent to mesh sizes of 2½, 4½, 5½ and 6½ inches. Models have been constructed for instantaneous natural mortality rates (M) of .12 and .20 and for growth rates observed in 1948-52 and in 1956. Broken lines of equal catch-per-unit-effort (Y/F) are shown.

Age composition and tagging studies are still inadequate for good estimates of mortalities. The size and age compositions for the periods 1948-49 and 1950-53 suggest estimates of 15% and 30%, respectively, for total mortality. An estimate of total mortality rate for the period 1955-56 was only 22% for ages 5 to 10 years (in 1955). This relatively low value resulted from the fact that abundance indices of two year-classes of large cod actually increased in 1956. Returns from the 1955 tagging in this area are incomplete. Preliminary analysis suggests that the total instantaneous mortality rate for tagged fish was about .60 (45%). The true total instantaneous mortality rate, as determined from age analysis, appears to have increased with the development of otter trawling to about .40 (33%). On these assumptions estimates of instantaneous tagging, natural, and fishing mortality rates in 1955-56 were each .20 (15%). Models have been calculated for instantaneous natural mortalities of .12 and .20, in order to cover the probable range of natural mortalities.

The two growth rates used in Figure 10 are based on the curves for 1948-52 and 1956, shown in Figure 9.

Selection curves for 2½, 4½, 5½ and 6½ inch mesh nets (ICNAF measure) were approximated by straight lines, with 50% retention lengths at 22, 38, 46 and 54 centimetres, respectively, to provide recruitment data (McCracken, 1957b).

An examination of the models shows that changes in growth or natural mortality can be expected to have marked effects on the stabilized yield. With a 4½ inch mesh, at instantaneous natural mortality rate (M) = .12 and instantaneous fishing mortality rate (F) = .24, an increase in growth such as that observed in 1955-56 would increase the yield by about 40%. A decrease in natural mortality from .20 to .12 would have a similar effect on yield at the fast growth rate.

If growth and natural mortalities remain constant, a change in fishing intensity can be expected to affect the long-term yield. Lines of equal landings per unit of effort have been drawn in order to see the relationship between total yield and catch-per-unit-effort. Catch-per-unit-effort decreases continuously as fishing intensity is increased. Total landings, on the other hand, increase to an optimum and then decrease with increased fishing. Such information is useful for a consideration of greatest profit to fishermen, consistent with maximum landings.

For given growth, natural mortality, and fishing mortality rates, the yield increases as mesh size is increased. The models show that the optimum mesh size is well above 6½ inches if growth is fast, or if growth is slow and fishing intensity is high. With slow growth and low fishing intensity optimum mesh size is about 5½ inches.

The calculated yields are based on catches rather than landings. They do not take account of the fact that some small

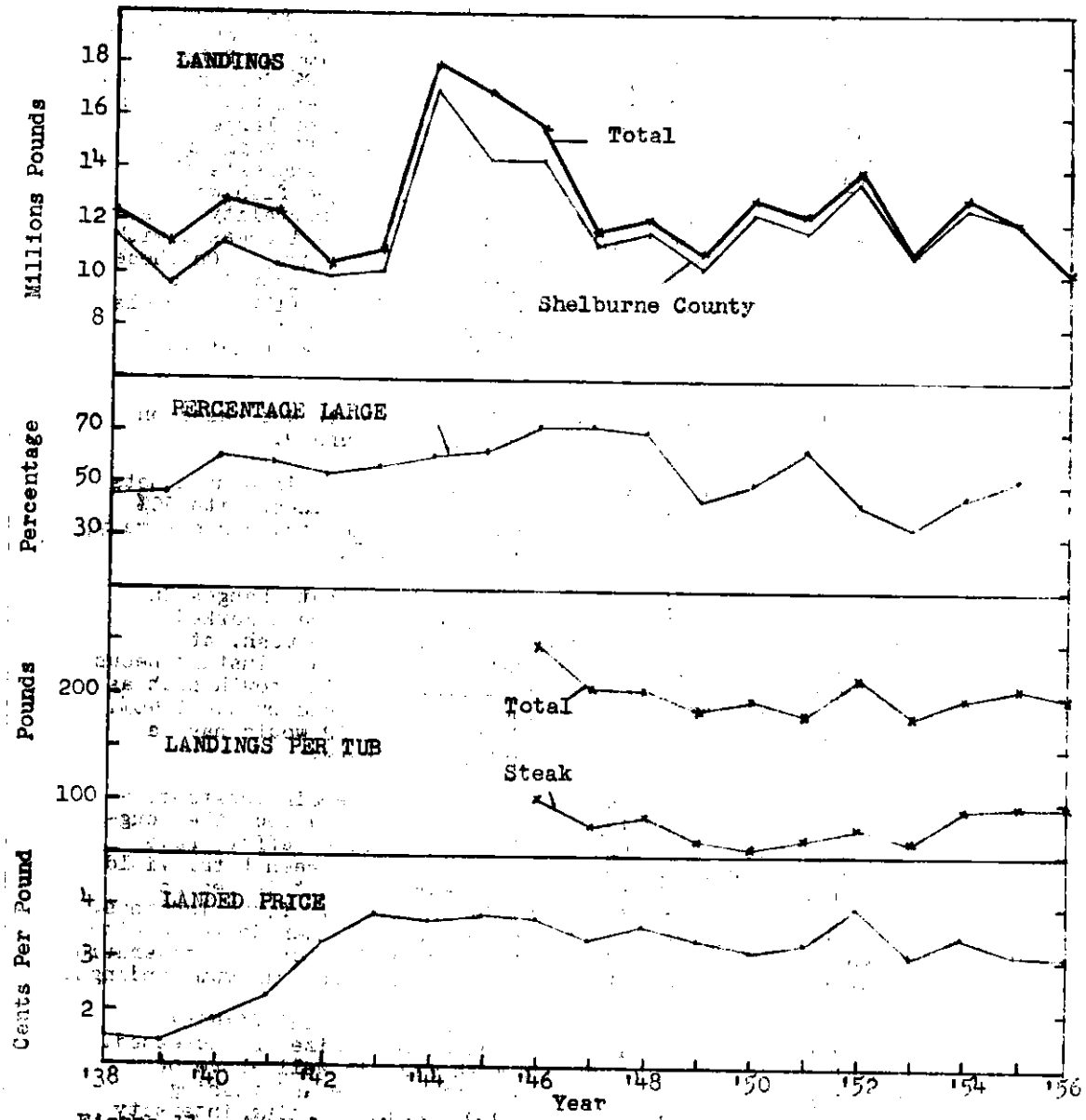

Figure 11. Annual variation in landings of Canadian and United States fishermen from the southern Nova Scotia unit area of subdivision 4X; percentage of large cod in United States landings from this area; landings per lb of line trawl of steak and total cod at Lockeport; and landed price per pound in Shelburne County, N. S.

cod are discarded at sea. Wherever such wastage at sea is substantial, the gain in yield with large mesh nets will be greater than that shown. Since the proportion of cod discarded is small as compared with haddock, we have chosen to ignore this added advantage of large mesh nets in the models.

The fluctuations in landings of subdivision 4T cod (Figure 4) are consistent with the effects of fishing intensity, size at first capture, and growth rate shown in the models. During depression years prices and landings were relatively low. During war years prices increased, and landings increased toward the optimum. It is assumed that fishing intensity increased with better prices. In post-war years fishing intensity increased, and the size at first capture was reduced as a result of the large-scale conversion from line fishing to otter trawling. During this period [illegible] landings and catch per unit of effort decreased. In the period 1950-55 growth rate increased, and landings increased to a record level [illegible].

On the basis of these studies of models and the history of the fishery, it is predicted that the average sustained yield can be increased by increasing mesh size well above the 4½ inch mesh size presently accepted for subarea 4. The optimum mesh size may be well above 6½ inches, but more precise information on mortalities is needed before the best size for first capture can be determined.

It will be impossible to measure the effect of the 4½ inch mesh size on landings of subdivision 4T cod. Only about half the small quantities of fish discarded at sea by Canadian otter trawlers in 1956 will be saved by the larger mesh. This saving will be small compared with natural fluctuations usually [illegible] variation in recruitment and growth. A much larger mesh size would have to be adopted to produce a measurable effect on landings.

Subdivision 4X cod

Landings. Most of the cod caught in subdivision 4X [illegible] been landed in Canada, and most of the Canadian landings have been in Shelburne County, Nova Scotia. Statistics of landings for the years 1938 to 1956 from the inshore grounds off Shelburne County (statistical unit area 4XO, including Roseway Bank) are shown in Figure 11. United States landings from these grounds have been relatively small throughout the period, and they have been less than one million pounds annually since 1946. Total landings varied between 10 and 14 million pounds annually during the years 1938 to 1942, and 1947 to 1956, but they were between 16 and 18 million pounds during the years 1944 to 1946. As noted above for subdivision 4T, and for subarea 4 as a whole, landings were unusually high at the end of World War II.

The proportion of large cod (over 10 pounds fresh, head-on, gutted) caught off southern Nova Scotia (Figure 11) was taken from United States statistics of landings at the

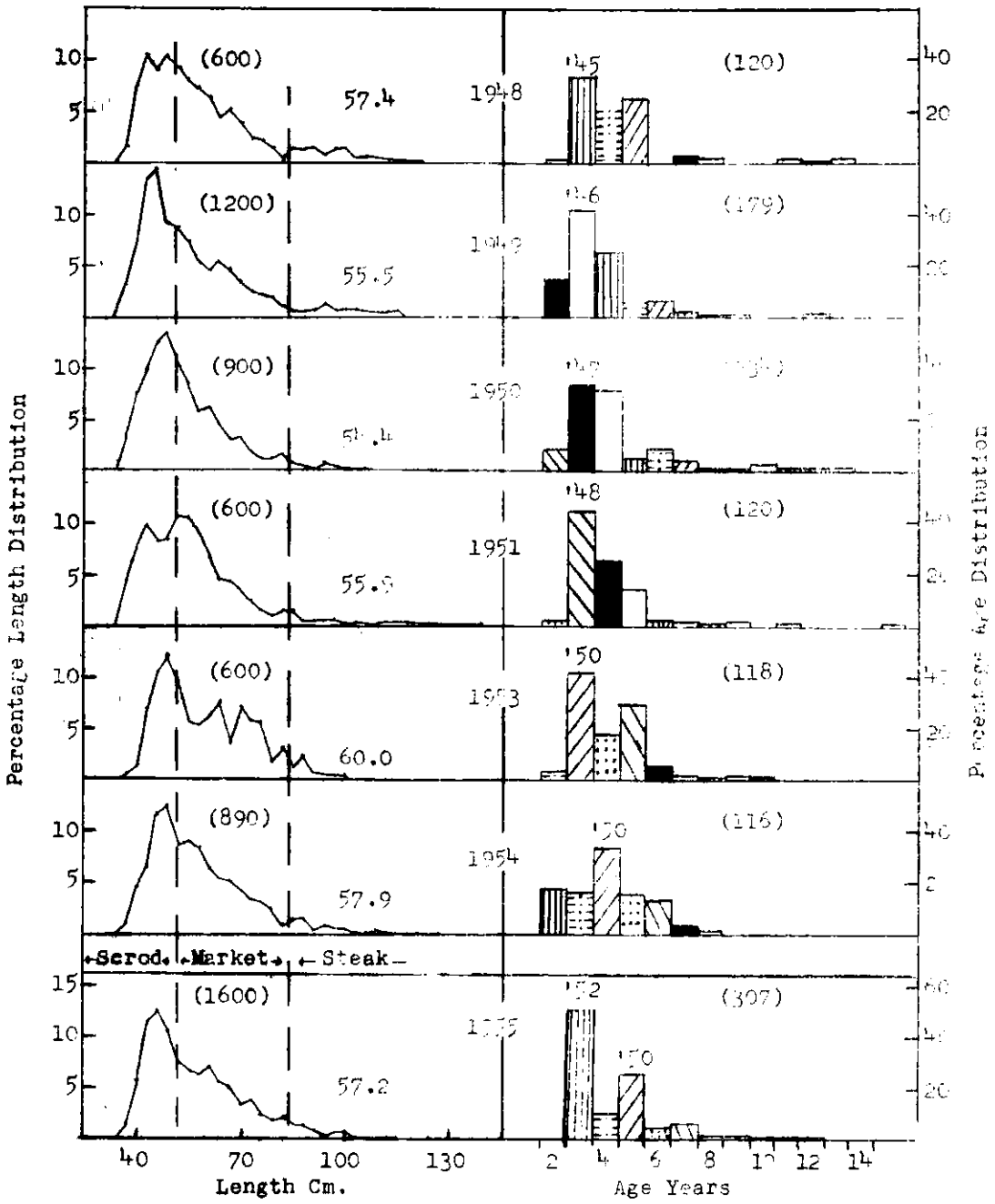

Figure 12. Percentage length and age distribution of cod landed at Lockeport, N. S., from inshore grounds during the quarter November to January, 1948 to 1951 and 1953 to 1955. Average lengths are noted, and numbers of fish measured and aged are recorded in brackets.

major New England ports. As in subarea 4 as a whole, the percentage of large cod increased during the latter part of the war, and the proportion of large cod was exceptionally high during the years 1946 to 1948.

Fishing effort records have been collected for more than half the boats landing at Lockeport, Shelburne County, since 1946. Landings by market categories, and numbers of tubs of gear fished have been recorded. A tub of gear represents an average of eleven 50-fathom lines, with about 50 baited hooks per line. The annual variation in landings per tub is shown in Figure 11. This index of abundance was highest when landings were highest in 1946 and 1952. Catch per tub of large cod, over 10 pounds, varied in the same manner as that of total cod.

Sizes and ages. The average sizes and ages of cod landed by hook-and-line fishermen from subdivision 4X differ in many respects from those landed by draggers from subdivision 4T (Figure 12). In general, the average length has been considerably smaller than that of Caraquet cod, and the modal length has been in the scrod market category, below 2½ pounds, fresh, gutted weight. Size composition has been more stable during the years 1948 to 1955 than that observed at Caraquet, New Brunswick.

The comparison of size compositions of Lockeport and Caraquet cod becomes more meaningful when interpreted in the light of age composition studies. Approximately one fifth of the cod measured were assigned to age groups by examining their otoliths. The cod fishery off Lockeport depends on much younger fish than that off Caraquet. Three-year-old cod contribute substantially to the fishery, and cod over 6 years are of small importance. As in the case of size composition, age composition has been more stable at Lockeport than at Caraquet.

The size and age compositions described represent those for the quarter November to January. There are some seasonal variations in sizes and ages of cod at Lockeport. During the months of February to April, larger cod are landed, although young, 4-year-old fish frequently dominate the landings. The older, mature cod spawn during this quarter. The proportion of large cod is considerably lower in the second and third quarters of the year (May to October) but 4-year-old cod continued to be dominant in landings. By the fourth quarter, November to January, younger, 3-year-old cod normally contribute the largest numbers to the fishery.

Sizes discarded. There is little information available concerning the quantities and sizes of cod discarded at sea on inshore grounds off Shelburne County. It has been noted above that most of the cod taken from this area have been caught by baited hooks. The smallest hooks used commercially for cod and haddock fishing in subarea 4, #17 Mustad or #6/0 Pflueger, are used at Lockeport. Fishermen have claimed that negligible quantities of cod are discarded at sea as too small for marketing. Studies of hook selection by McCracken (1957) support this contention, in that the smallest cod taken with #17 hooks

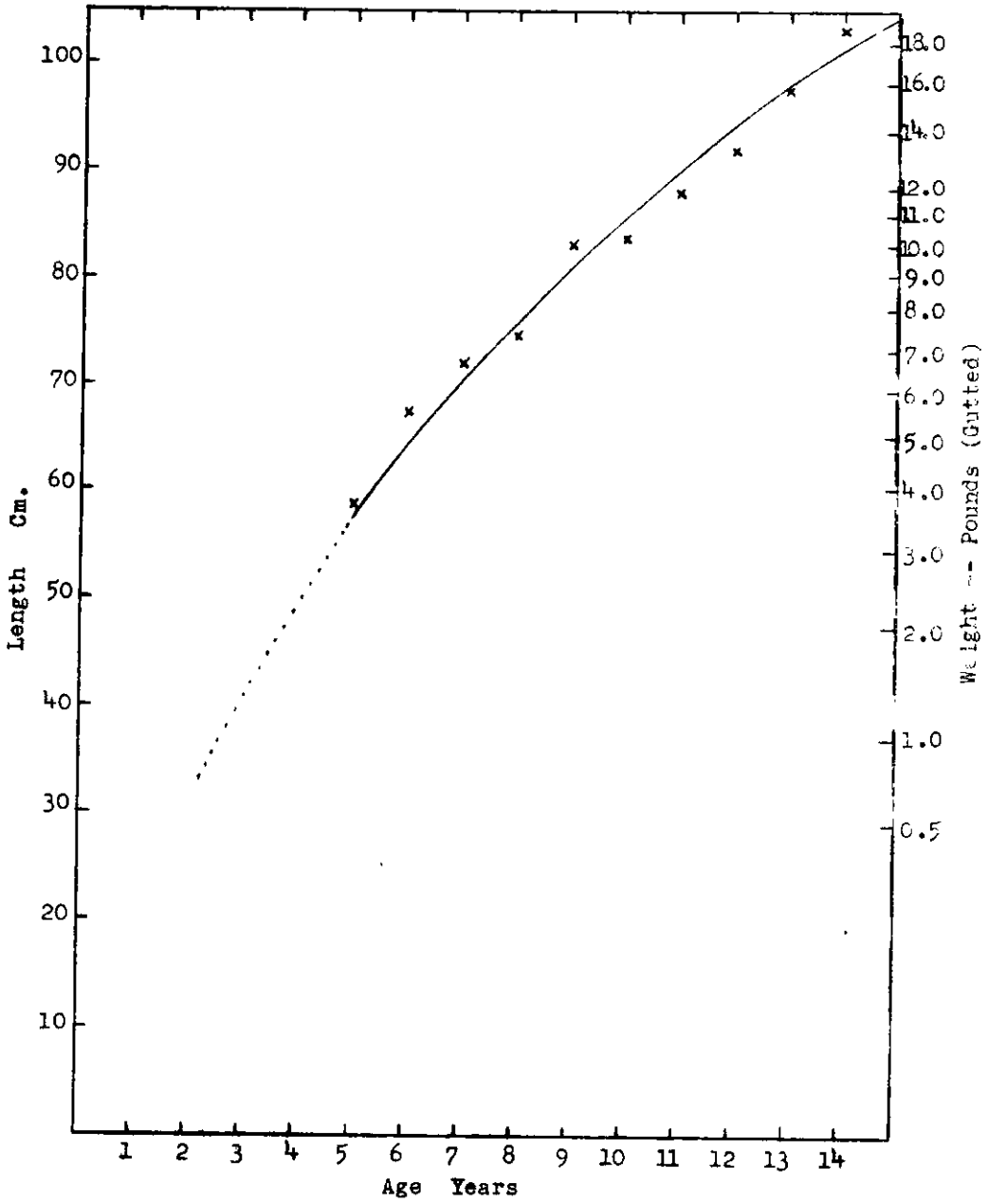

Figure 13. Growth in length of cod landed from inshore grounds at Lockeport, N. S., by line fishermen during the years 1947 to 1956. Observed average lengths and a Bertalanffy growth curve are shown for the February to April quarter. An equivalent weight scale has been added.

were 31 centimetres long. Very few cod were smaller than the smallest 36 centimetre cod in commercial landings.

In 1953 a few observations on discards were obtained from data collected during bait experiments at Lockeport (Martin and McCracken, 1954). In April, 1953, a sample of cod measured at sea had a mean length of 62 centimetres, and 43% of the fish were of scrod size, below 49 centimetres. A commercial sample taken at Lockeport at the same time had a mean length of 65 centimetres and 19% of the fish were scrod.

Some cod are discarded at sea in the southern Nova Scotia area, but the proportion wasted is much smaller than that observed in dragger fishing off northern New Brunswick. The proportion discarded by line fishing is believed to be small. The proportion discarded by otter trawlers in subdivision 4X is unknown, but we do know that the total catch by this method is relatively small, and the proportion of large fish (over 10 pounds) in the landings has averaged about 50% by weight during the past 20 years. Most of these trawl cod were caught in deep water, incidental to fishing for redfish.

Growth. The growth rate of southern Nova Scotia cod is described in Figure 13. Since no change in growth rate comparable with that of subdivision 4T was observed, one growth curve is shown, representing average growth during the years 1947 to 1956. The February to April quarter was selected because it was a period of good sampling, growth stagnation, and large numbers of year-classes. A Bertalanffy growth curve was calculated from the observed mean lengths of each age group.

Examination of 325 gonads collected at Freeport, Nova Scotia, from subdivision 4X cod, showed that the size at which 50% matured was about 66 centimetres for males, and about 70 centimetres for females. Growth rate appears to decrease more rapidly beyond maturity, at 6 to 7 years.

Cod have been longer for a given age in landings from subdivision 4X than in those from subdivision 4T, even in the years 1955-56 when cod growth in the Gulf of St. Lawrence was most rapid.

Growth in weight is fastest in young cod. Growth does not drop below 50% by weight per year until after the age of 5 years (58 centimetres or 3½ pounds). It will be noted below that losses by natural mortality are much smaller than gain by growth. It is accordingly believed to be advantageous to leave small, fast-growing cod in the water until growth begins to slow down. The best size for first capture is undoubtedly well above the smallest sizes now landed from southern Nova Scotia grounds.

Tagging. The distribution of recaptures from the only post-war tagging of southern Nova Scotia cod in June to October, 1953, is shown in Figure 14 (McCracken, 1956). Recaptures were mainly taken by line fishermen from neighbouring inshore grounds. In contrast to the extensive seasonal migrations of cod observed

(McCracken,1956)

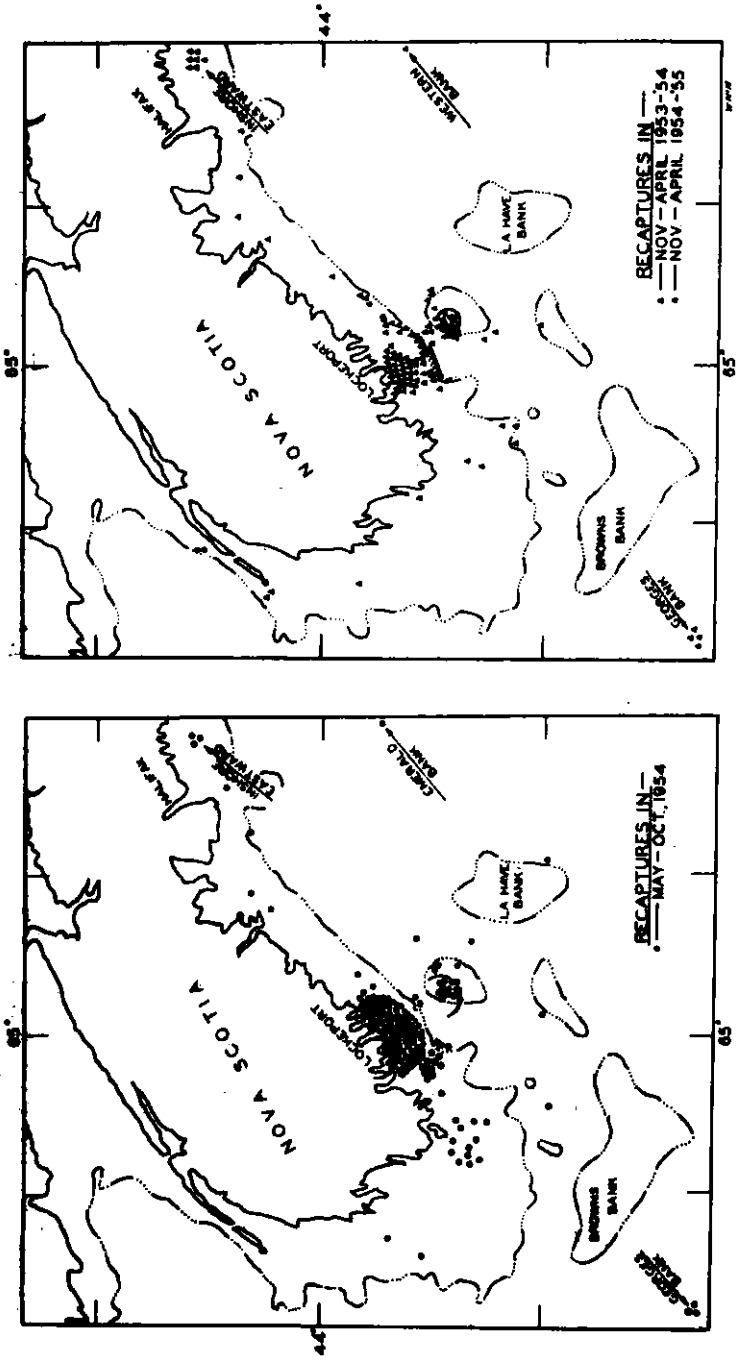

Figure 14.

in the Gulf of St. Lawrence, the Lockeport tagging indicated no pronounced seasonal movements. However, more cod were recaptured deeper, at about 50 fathoms, during "winter" months.

There was a considerable amount of seasonal variation in the numbers of tags returned (Table II). Most tags were recovered during "summer" months. Although large quantities of cod were caught during the "winter" season, the numbers of tags returned then were very small. The results of pre-war tagging by McKenzie (1956) indicate that the cod that move into the Lockeport area during the "winter" months live to the east of the Shelburne County area in inshore waters during "summer" months.

It appears that this southern Nova Scotia cod fishery depends largely on a resident stock of cod which does not contribute to the cod fisheries of other areas. The fishery during "winter" months takes large numbers of cod which move into the Lockeport area.

The number of tag recoveries, by type of tag and by season and year, is summarized in Table II. The intensity of the fishery, and the high importance of fishing mortality, relative to natural and tagging mortality, is shown by the fact that 60% of the disk tags have been recovered.

Table II. Recoveries from cod tagged off Lockeport, N. S. in May to October, 1953.

Recoveries from 608 disk tags.

Year	May-Oct.	Nov.-Apr.	Total
1953-4	171 (28%)	65 (11%)	236 (39%)
1954-5	105	6	111
1955-6	8	3	11
1956-7	4	1	5
Total	288 (47%)	75 (12%)	363 (60%)

Recoveries from 933 Lea hydrostatic tags.

1953-4	152 (16%)	76 (8%)	228 (24%)
1954-5	77	2	79
1955-6	3	0	3
1956-7	1	0	1
Total	233 (25%)	78 (8%)	311 (33%)

Factors affecting landings. Some of the effects of the environment and fishing on landings of cod from subdivision 4X are considered under the headings "recruitment", "landed price" and "model".

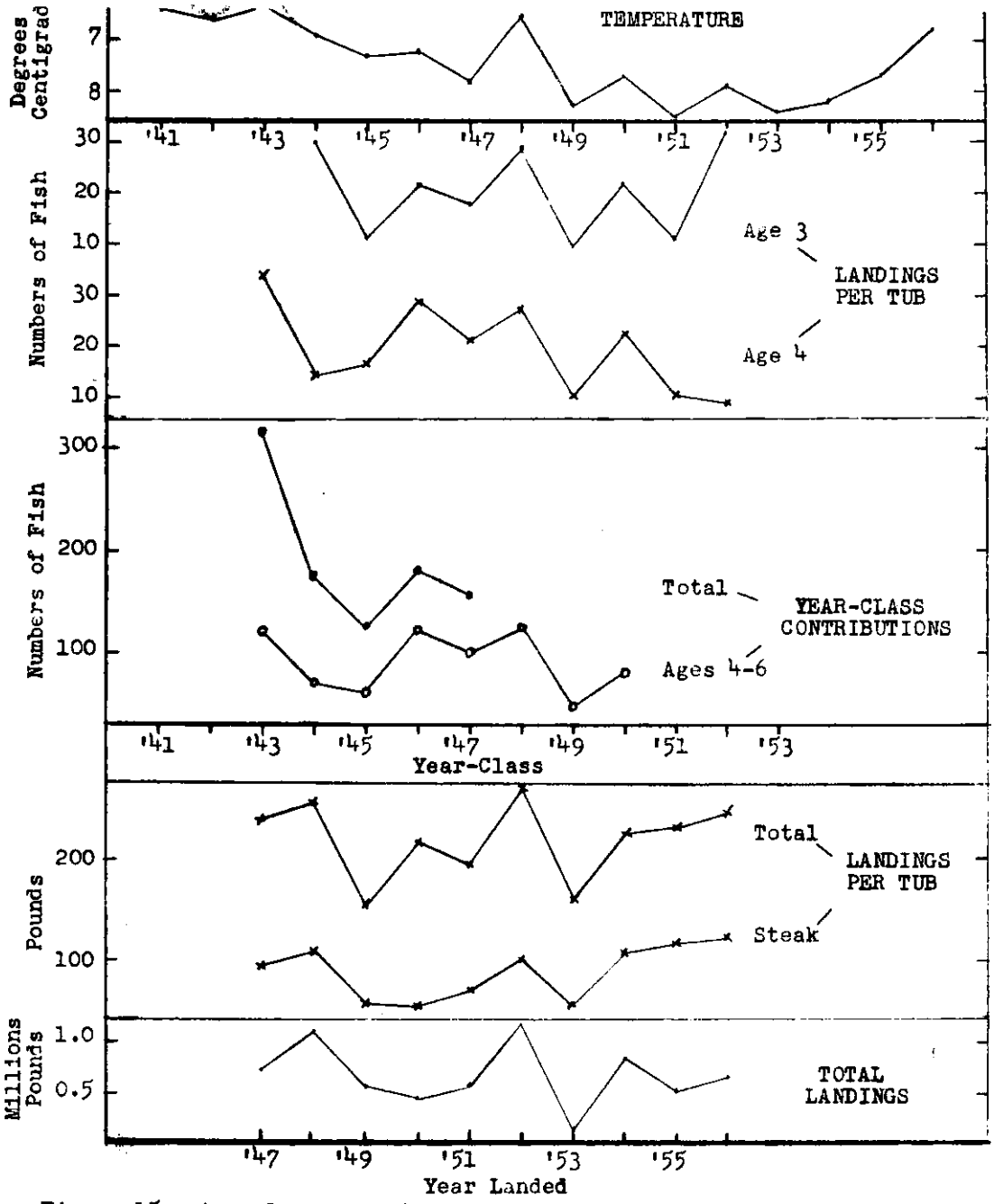

Figure 15. Annual mean surface water temperatures at St. Andrews,N.B., in subdivision 4X (scale reversed); numbers of 3- and 4-year old cod landed per tub of gear fished by year-classes on inshore grounds off Lockeport, N.S., during the November to April season; numbers of cod contributed as 4- to 6-year-olds and total contributions by year-classes; annual landings of total and steak cod per tub of gear, and total landings by the same Lockeport boats, with the scale shifted by 4 years.

(a) Recruitment. In the southern Nova Scotia area cod grow rapidly. They enter the fishery in large numbers at the age of 3 and most of the cod die, largely because of fishing, by the age of 6. Under these circumstances, it has been possible in 10 years to examine the abundance of a number of year-classes just after recruitment to the fishery. For a few year-classes we have determined the total contribution to the "Lockeport" fishery. Recent fluctuations in year-class strength are considered in relation to mean surface water temperatures on the one hand, and in relation to landings on the other.

Indices of abundance and sampling of landings at Lockeport, Nova Scotia, are most useful for this study during the "winter" months of November to April. Most of the "winter" fishing has been carried out in inshore waters, and the indices of abundance, therefore, refer specifically to inshore cod. Sampling has been more extensive during this season.

Fluctuations in year-class strength are shown in relation to water temperatures and landings in Figure [illegible]. Water temperature variation in water temperatures is represented by annual mean surface temperatures at St. Andrews, New Brunswick, in statistical division 4X. Hachey and McLellan (1948) have shown that these temperatures are generally indicative of variations in the surface water conditions over the main portion of the Atlantic coast of North America. The temperature scale has been reversed for convenience in consideration of the relationship between temperature and recruitment. Indices of abundance of year-classes at recruitment to the fishery are represented by landings in numbers-per-tub of 3- and 4-year-old cod by part of the Lockeport fleet of boats in the months of November to April. Contributions of 4- to 6-year-old cod are shown for the year-classes 1943 to 1950, and total contributions are shown for the year-classes 1943 to 1947. Landings in pounds per-tub-of-gear fished, and total landings by the "Lockeport" boats involved in this study, are recorded for the years 1947 to 1956.

There was a close relationship between variations in temperature during development and variations in the abundance of cod recruited to the fishery (Figure 15). Recruitment was relatively high when water temperatures were relatively low. Conversely, recruitment decreased during relatively warm years. However, it should be noted that although water temperatures increased during the 1943 to 1952 period, recruitment did not show a similar gradation. Some such factor as variation in spawning time might be of importance here.

Fluctuations in total contributions of 4- to 6-year-old cod conformed with variations in abundance indices at recruitment. Total contributions of year-classes also varied in a similar manner, but the 1943 year-class contributed more old cod than subsequent year-classes, possibly because of less intensive fishing.

These fluctuations in year-class strength follow the same pattern as variations in weight landed per-tub-of-gear fished, and in total weight landed (Figure 15). In this

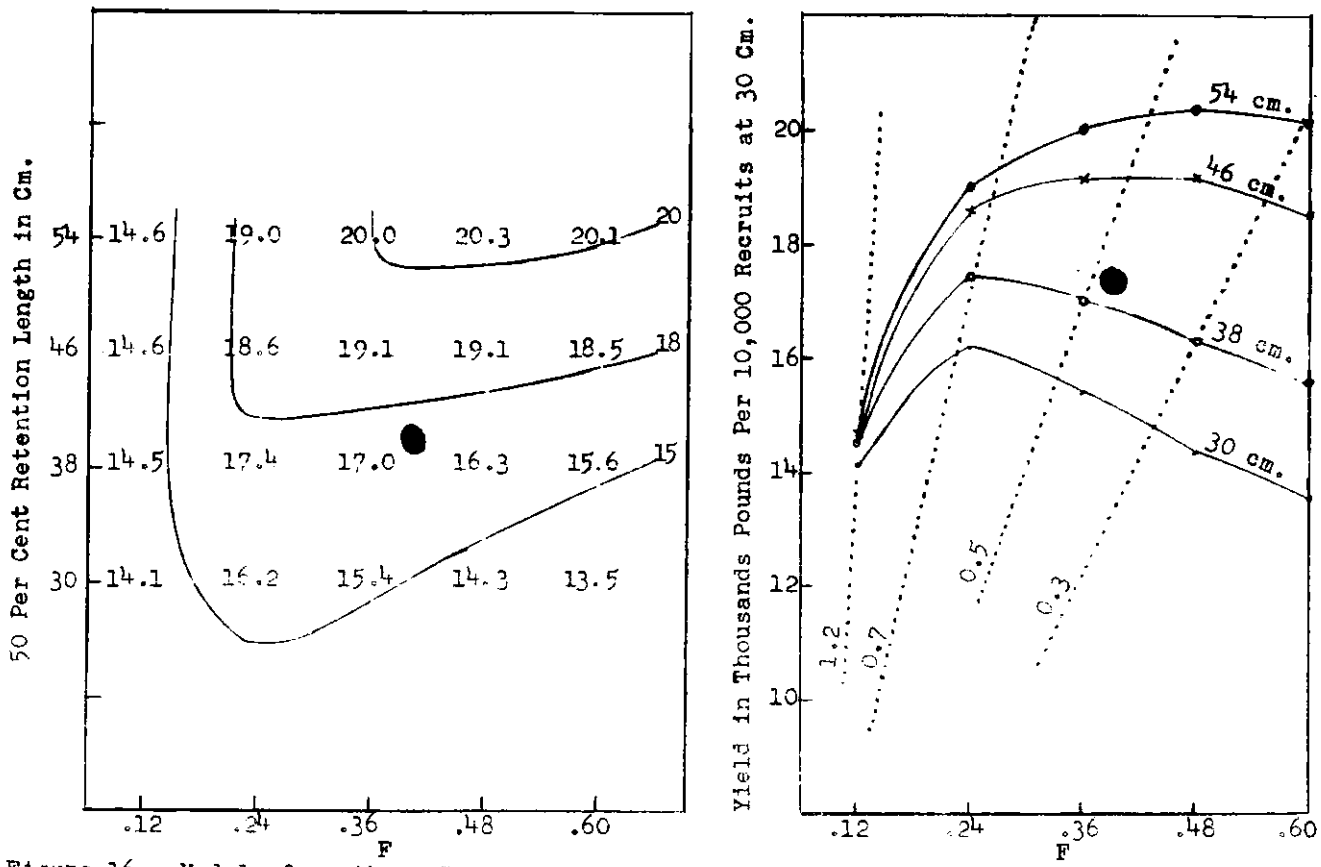

Figure 16. Models of southern Nova Scotia cod fishery in subdivision 4X, relating yield per 10,000 recruits at 30 cm. to instantaneous fishing mortality rate (F) for 50% retention lengths at 30, 38, 46 and 54 cm. The model is based on an instantaneous natural mortality rate (M) of .20 and the growth rate described in Figure 15. The model is presented in two forms, with isopleth yield curves on the left and yield curves on the right. A point representing post-war size at first capture and fishing intensity is marked on the model. Broken lines of equal catch-per-unit-effort (Y/F) are shown.

comparison the landings are out of phase with year-classes by 4 years since 4-year-old cod are normally dominant in landings. Variations are not expected to correspond closely in such years as 1947, when landings included more old cod. Fluctuations in landings by the "Lockeport" boats conform with the variations in total landings presented in Figure 11.

It is concluded that annual variation in year-class strength has been a factor of primary importance in post-war fluctuations in landings of cod from the southern Nova Scotia area.

Year-class strength has been correlated with water temperatures, but the relationship is not fully understood. Cod larvae may have a better chance for survival in this area when water temperatures are relatively low. Alternatively, the basic factor involved may be annual variation in the movement of water over the Scotian Shelf during the early pelagic life of cod.

(b) Landed price. Landings of inshore cod in Shelburne County have been positively correlated with landed price. Annual landings varied between 99 and 171 million pounds when landed price was 3 to 4 cents per pound. Landings varied between 55 and 132 million pounds when landed price was 1 to 2 cents per pound. In general, both landings and landed price have increased during the period 1921 to 1953. As observed by Gordon (1955) fluctuations in cod landings have been partially affected by economic factors.

The average annual landed prices of cod in Shelburne County are shown in relation to landings for the period 1938 to 1956 in Figure 11. The highest landings were made when landed prices were highest, but landings and landed price were not closely correlated during this wartime and post-war period.

As noted above for subdivision 4T, landings and landed price of cod were lower between the two World Wars than they were during and after World War II. Although landings have been correlated with landed price, it is clear that other factors have been responsible for large fluctuations in landings.

(c) Model. In order to consider the effects of size at first capture and fishing intensity on the yield of subdivision 4X cod, a model of the "Lockeport" cod fishery has been drawn up. It is presented in two forms in Figure 12. Relative yields of cod have been determined for one level of natural mortality, one growth rate, four sizes at first capture, and five levels of fishing intensity. In one panel an isopleth model is shown. In the other, yield curves are presented for the various sizes at first capture, and lines representing three levels of catch-per-unit-effort are shown.

Yields were calculated on the basis of 10,000 cod, fully recruited to the fishery at 30 centimetres. As noted above, this is the size at which cod first enter the commercial fishery in southern Nova Scotia. Cod are normally not fully recruited until they reach a length of about 45 centimetres.

A 50% retention length of about 40 centimetres would appear to describe the selection of "Lockeport" cod. Because of the lack of precise information on discards of cod, we have chosen to use a lower size for recruitment. The general conclusions are not affected.

Paloheimo (1957) has used the catch-per-unit-effort, age composition, and tagging data described above to determine natural and fishing mortalities of "Lockeport" cod. The total instantaneous mortality rate was estimated to be about .60 (45%) for the "summer" seasons. This gave values of .07 (5%) for instantaneous natural mortality rate and .53 (40%) for instantaneous fishing mortality rate. Since this does not take account of tagging mortality, an even lower natural mortality rate is implied. A consideration of confidence limits places the instantaneous natural mortality rate between .00 (0%) and .20 (18%). Fishing mortality was high during the months of May-August, and low during the rest of the year when fishing moved to deeper water, and a different population of cod moved into the area. The estimates of mortality rates were further obscured by the sudden decrease in numbers of recovered tags in the second and third years after tagging, possibly because of losses of tags under conditions of rapid growth. The instantaneous natural mortality rate used in the model was .20.

The growth rate used in calculating the model was based on the Bertalanffy curve shown in Figure 13.

The 50% retention lengths of 30, 38, 46 and 54 centimetres correspond with mesh sizes of $3\frac{1}{8}$, $4\frac{1}{8}$, $5\frac{1}{8}$ and $6\frac{1}{8}$ inches. Most of the "Lockeport" cod are caught on #17 Mustad hooks, and these have a 50% retention length, comparable with a $4\frac{1}{8}$ inch mesh, at about 38 centimetres (McCracken, 1957[a]).

A point describing the estimated post-war size at first capture and fishing intensity is marked on the model. The model shows that catch-per-unit-effort and landings can be increased by decreasing fishing intensity, or by increasing size at first capture. The greatest benefit is expected to result from an increase in size at first capture. This might be achieved by using a larger hook size in line fishing and a larger mesh size in otter trawling. If the instantaneous natural mortality rate is lower than .20, we can see from Figure 10 that the benefit of reduced fishing, or larger hook and mesh sizes, would be greater than that shown in Figure 16.

Since data are lacking on the effects of density on natural mortality and growth, optimum size for first capture has not been estimated. Only the direction of change for greater yields is clear.

The wartime increase in landings, shown in Figure 11, is consistent with the effects of changes in fishing shown in the model. During the years 1942 and 1943 fishing by United States otter trawlers declined. In Canada, the number of men fishing and the number of tubs of trawl, as shown in annual

fisheries statistics for Shelburne County, declined substantially in the years 1941 to 1943. The net result was a decrease in fishing effort, a possible net increase in size at first capture, and a slight reduction in total landings. In 1944 to 1946 the yield was substantially above the long-term average, catch-per-unit-effort was higher than during post-war years, and the average size of cod increased. In post-war years, as fishing intensity increased, landings, catch-per-unit-effort, and average size of cod reverted to pre-war levels.

It might be argued that a few good year-classes could have produced the increased landings observed during the latter part of the war. This appears unlikely since landings increased during the same years in subdivision 4T and in subarea 4 as a whole, as in subdivision 4X, and the year-classes involved must have differed greatly from one area to another because of the very different growth rates in the different populations.

On the basis of these studies of a model and of the history of the fishery, it is predicted that the long-term sustained yield could be increased in subdivision 4X by increasing hook and mesh sizes, or by decreasing fishing intensity.

Management

Now that it has been predicted that the optimum size for first capture of subarea 4 cod is considerably higher than the 38 centimetres retention length already accepted by ICNAF, it is desirable to give consideration to some of the practical problems involved in a further increase in gear selection. In the first place, we are interested in the equivalent mesh sizes and hook sizes for a series of cod sizes which have commercial or biological significance. Secondly, we are concerned with the effects of advantageous changes in cod-fishing gear on other species which are caught with cod.

In Table III a series of cod lengths are listed which have commercial and biological significance. The mesh and hook sizes which provide 50% retention of fish at these lengths are also listed. The data on selection factors for cod with manila codends, and 50% retention lengths for cod with a few of the standard commercial hooks, are taken from McCracken (1957). He has shown that the selection factor (50% retention length/equivalent manila mesh size) for cod is about 3.3, and that the smallest standard commercial hook size, #17 Mustad, is approximately equivalent in selective properties for cod to a $4\frac{1}{2}$ inch manila mesh size (ICNAF measure).

The $4\frac{1}{2}$ inch mesh size accepted for subarea 4 and the #17 hook size select cod at the smallest marketable size of cod in Canada. Since smaller cod are not normally taken in very large numbers by the commercial fleet, the protection offered to cod by this gear selection is small and the advantages are not measurable.

Table III. Equivalent mesh and hook sizes for a series of cod sizes which have commercial or biological significance.

Cod length	Commercial significance	Biological significance	Equivalent manila mesh size (ICNAF measure)		Approximate equivalent hook size (Mustad)
cm.			In.	(mm.)	
22	...	Smallest cod caught in otter trawls	2.6	(67)	...
33	...	Smallest cod caught on baited hooks	3.9	(100)	#17
38	Smallest cod landed in Canada	ICNAF recommendation (1955)	4.5	(114)	#17
43	Small scrod (1½ pounds fresh); Tinker -- small cull (salt fish)	...	5.1	(130)	#15
46	...	Low optimum size for first capture	5.5	(139)	#14
51½	Scrod -- market cull (2½ pounds fresh) (large increase in price/pound)	...	6.1	(156)	#13
54	...	Intermediate optimum size for first capture	6.5	(165)	#12
63	...	High optimum size for first capture	7.5	(190)	#11
65	Small -- medium cull (salt fish) (5 pounds fresh)	...	7.8	(197)	#11

The 5½ inch mesh and #14 hook sizes have a 50% retention length for cod at about 46 centimetres. This fish size is in the low-priced, small (scrod) market category. It is predicted that selection at this fish size would have little immediate effect on total landed value of cod, and that the long-term yield would be higher than that observed under present environmental and fishing conditions.

A 6½ inch mesh and a #12 hook would release all the scrod and the smallest medium cod. For subarea 4 as a whole the total landings and total landed value are predicted to be still higher for selection at this level. Only under conditions of low fishing intensity would we not expect increased landings.

A 7½ inch mesh and a #11 hook would provide a 50% retention length for cod at about 63 centimetres. This length is close to the Canadian cull between small and medium market categories for green-salted cod (about 5 pounds fresh, head-on, gutted weight). The optimum size for first capture of cod may well be this high in subarea 4 but more information is needed. It is of interest to note that the 1956 Report of the Ad Hoc Committee of the Permanent Commission claims an optimum mesh size for North Sea cod of about 200 millimetres (8 inches).

In general then, size at first capture of subarea 4 cod can be increased to at least 50 centimetres with a small immediate loss in total landed value and a substantial long-term increase in total landings of larger, more valuable cod. This increase can be achieved with a mesh size of 6 inches and a hook size of about #13 Mustad.

If size at first capture of cod were increased to 50 centimetres by controlling the sizes of meshes and hooks, what would be the effects on landings of other groundfish species? In order to give superficial consideration to this problem, subarea 4 landings of groundfish by species, subdivisions, and countries have been summarized for the years 1954 and 1955 (Figure 17).

In the Gulf of St. Lawrence area (subdivisions 4R, 4S and 4T) the dominant species is cod. Haddock is of relatively low importance in the area, and almost all the catch is taken from the southern part of subdivision 4T. The redfish catch is substantial, but this species is caught in deep water by otter trawlers fishing specifically for this species. Negligible quantities of redfish are landed with landings of cod. Large catches of flounders, mainly American plaice, Hippoglossoides platessoides (Fabricius), are taken from subdivision 4T incidental to dragging for cod. The only other species of importance in groundfish landings from the Gulf of St. Lawrence is hake, Urophycis tennis (Mitchill), most of which are caught on baited hooks in the southern part of subdivision 4T.

In subdivisions 4V to 4X, which include the offshore Nova Scotia banks, the species composition of groundfish landings is more mixed than that of the Gulf of St. Lawrence. Haddock and pollock are of much greater importance. In fishing for cod, haddock and flounders contribute substantially to the total landings.

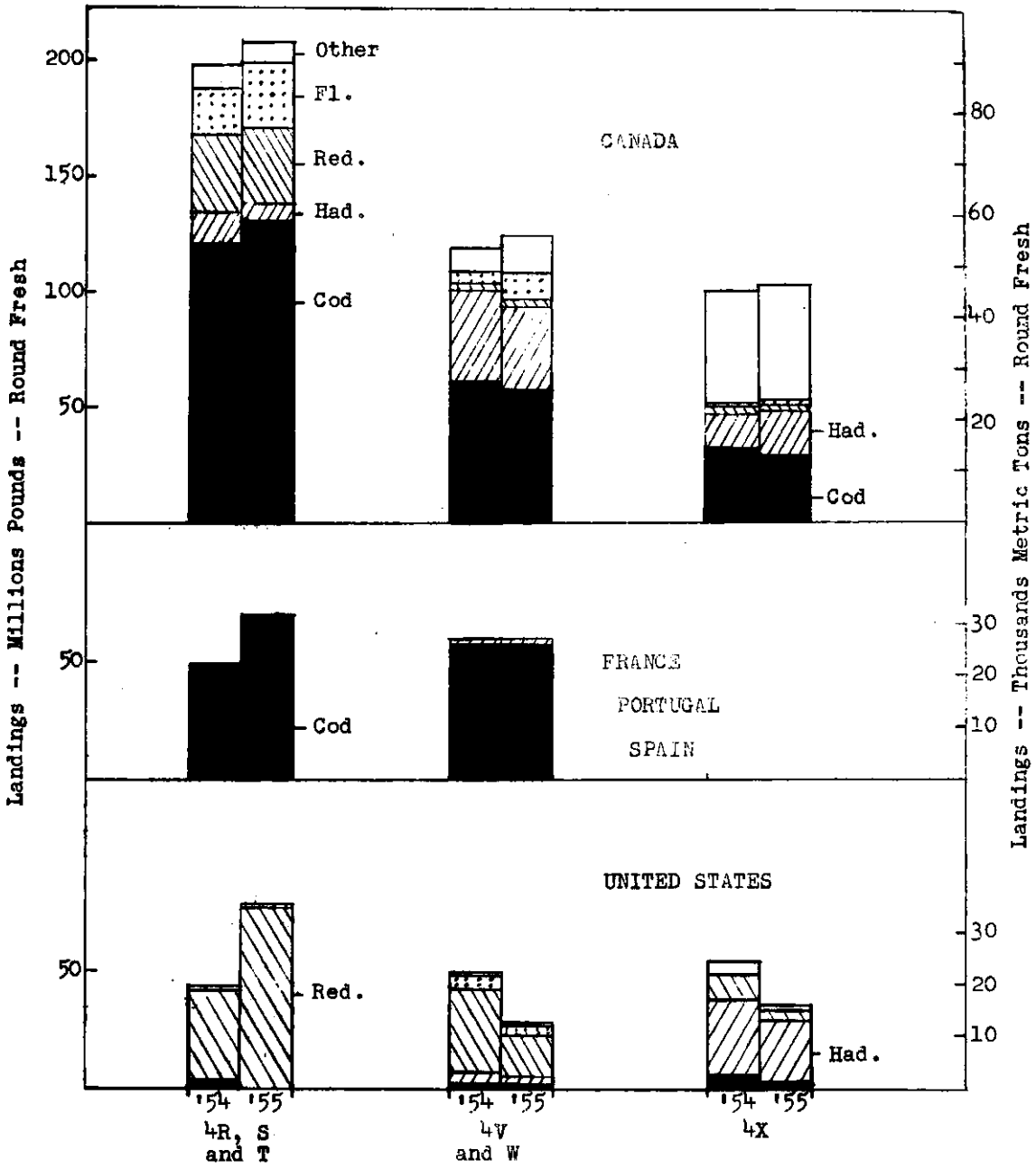

Figure 17. Groundfish landings for the years 1954 and 1955 from groups of subdivisions of subarea 4 by countries and by species (cod, haddock, redfish, flounder and others).

Species composition of these groundfish landings differs from one country to another. The European countries, France, Portugal and Spain, have been primarily interested in cod, and particularly large cod, for salting. The United States has been most interested in redfish and haddock during recent years. Canadian landings have been primarily cod, but about half the total groundfish landings have been other species, with haddock second to cod.

In recommending a 4½ inch mesh size for haddock fishing in subarea 5, Graham (1952) has pointed out that this is but a first step in management. A second step to about 5½ inch mesh (age 3 years and 50% retention at 44 centimetres) has been advocated by scientific advisers to ICNAF Panel 5 to further increase haddock landings. Optimum size for first capture of subarea 4 haddock may also well be about 44 centimetres (equivalent mesh size 5½ inches and equivalent hook size #17) (Doc. 8, ICNAF, 1955). An increase in mesh size for subarea 4 cod to 5½ inches is thus expected to have a beneficial effect on landings of haddock. The equivalent hook size for cod (about #14 Mustad) might be too large for haddock fishing, but this may prove to be of little concern since most of the subarea 4 haddock are now caught in otter trawls.

Subarea 4 redfish are of little concern here since they are mainly caught independently of cod and haddock.

McCracken (1957[c]) has demonstrated a selection factor of 2.0 for plaice taken in manila codends, and similar selectivity for other flounders. The minimum size of plaice culled for commercial landings in Canada is about 35 centimetres. Under these circumstances, none of the marketable sizes of plaice would be lost to commercial landings by adopting a mesh size as high as 6½ inches. A similar conclusion presumably applies to other offshore flounder species. Since most flounders are taken in otter trawls, hook selection is of little concern for these species.

It is concluded that landings of the other major groundfish species would not decrease by the adoption of a 5½ or 6 inch minimum mesh size in otter trawls used for cod-fishing in subarea 4. In the case of haddock, such action would probably increase landings.

Research

Fluctuations in landings of subarea 4 cod have been related to both environmental factors and effects of fishing, but their relative importance is not yet clear. There is need for intensive research on cod and other groundfish species to permit more precise predictions of landings and improved estimates of the effects of restrictions on fishing practices on the maximum sustained yield of cod and other groundfish

species. Research should be intensified along the following lines:

(1) Statistics -- (a) Statistics of past landings by European vessels should be obtained from log books and landing records of individual trips.
(b) Indices of abundance should be studied thoroughly in order to obtain a better understanding of fluctuations in stocks.

(2) Sampling -- (a) Better data are needed on the size and age composition of stocks and landings.
(b) Information on the quantities and sizes of groundfish caught and discarded at sea is required particularly.

(3) Ecology -- (a) The pelagic and deep-water distribution of groundfish is not sufficiently well known. Further exploration is needed to determine the relation of fishing to total stocks.
(b) What are the environmental factors controlling the distribution of groundfish?

(4) Recruitment --(a) What are the effects of temperature and larval drift on the strength of year-classes entering the fishery?
(b) Under what fishing conditions can we expect optimum long-term recruitment?

(5) Growth -- (a) Special sampling of small unmarketable fish is required for more complete growth curves.
(b) To what extent is growth dependent on climate, food and density?

(6) Natural mortality -- (a) It is important to determine the magnitude and variations of natural mortality at the smallest fish sizes now caught, under conditions of reduced fishing intensity.
(b) Is natural mortality density dependent?

(7) Fishing mortality -- Tagging studies should be continued to provide data on mortalities.

(8) Food -- What is the extent of annual variation in the abundance and availability of groundfish food supplies?

(9) Competition -- A study of fish food of various sizes and species of groundfish will provide data on competition and predation.

(10) Selection -- The selective properties of various hook sizes and of trap nets are poorly understood.

(11) Models -- The effects of size at first capture and fishing intensity on long-term landings from representative populations of the major groundfish species can be better understood by the construction of models. There is need for more intensive work in this field.

A research program of this magnitude is expensive and long-term, and predictions of the effects of management of the fisheries will improve very slowly. In some cases the process can be speeded up by considering the odds in favour of restricting fishing operations, and on this basis introduce experimental regulations which can be adjusted in accordance with observed changes in the fisheries. This has been the approach to management of subarea 5 haddock, and the principle should be extended to subarea 4 cod, if methods of measuring the effects of management can be developed. Research effort should accordingly be concentrated on projects which will provide base-line information in sufficient detail to permit evaluation of the effects of management. From this point of view, we should place research emphasis on detailed statistics and sampling of commercial catches, and the relation of these catches to total stocks. The effects of environmental factors on landings should be determined as precisely as possible in order to improve the evaluation of the effects of changes in size at first capture or fishing intensity on the yield from the fisheries.

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References

Fisheries Statistics of Canada, 1913-56. Dominion Bureau of Statistics, Ottawa.

Fishery Statistics of the United States, 1938-55.

Gordon, H. Scott. 1955. Economic factors in catch fluctuations. J. Fish. Res. Bd. Canada, 12(1):85-92.

Graham, H. W. 1952. Mesh regulations to increase the yield of the Georges Bank haddock fishery. Inter. Comm. for the Northwest Atl. Fish., Second Ann. Rept. for 1951-52, pp. 23-33.

Graham, Michael. 1956. Sea Fisheries. Their investigation in the United Kingdom. E. Arnold, London.

Hachey, H. B. and H. J. McLellan. 1948. Trends and cycles in surface temperatures of the Canadian Atlantic. J. Fish. Res. Bd. Canada, 7(6):355-362.

Hansen, Paul M. and F. Hermann. 1953. Fisken og Havet ved Grønland. Skrifter fra Danm. Fiskeri -og Havunder-søgelser, Nr. 15, Kobenhavn.

International Commission for the Northwest Atlantic Fisheries. 1952. Second Ann. Rept. for the year 1951-52, Part 4, Statistics of landings of groundfish from the Convention Area.

International Commission for the Northwest Atlantic Fisheries. 1954-57. Stat. Bull. Vol. 2-5, for the years 1952-55.

Lauzier, L. 1953. Coastal station data, Atlantic Coast. Ms. Rept. No. 537, Atlantic Oceanographic Group, St. Andrews, N. B.

Lauzier, L. 1954. Recent surface water temperatures along the Canadian Atlantic coast. Cold years -- Warm years. Fish. Res. Bd. Canada, Atl. Prog. Rept., No. 58, pp. 6-11.

Leim, A. H. 1955. Herring mortalities in the Bay of Chaleur in 1955. Fish. Res. Bd. Canada, Atl. Prog. Rept., No. 62, pp. 30-32.

Marcotte, A. 1955. Rapport préliminaire de la station de Biologie Marine. Rapport général du Département des Pêcheries de la Province de Québec, 1953-54. Contr. Dépt. Pêch., Québec, No. 46.

Martin, W. R. 1953. Long-term prediction based on climatic changes. Paper presented to Comm. Biol. Invest., Ann. Meeting Fish. Res. Bd. Canada (unpub. Ms.).

Martin, W. R. and F. D. McCracken, 1954. Relative efficacy of baits for groundfish. Fish. Res. Bd. Canada, Atl. Prog. Rept., No. 50, pp. 17-21.

McCracken, F. D. 1956. Cod and haddock tagging off Lockeport, N. S. Fish. Res. Bd. Canada, Atl. Prog. Rept., No. 64, pp. 10-15.

McCracken, F. D. 1957[a]. Hook selection for cod and haddock. Paper submitted to Joint Scientific Meeting of ICES/ICNAF/FAO, 1957.

McCracken, F. D. 1957[b]. Selection factors for cod and haddock with codends of different materials. Paper submitted to Joint Scientific Meeting of ICES/ICNAF/FAO, 1957.

McCracken, F. D. 1957[c]. Selection by large mesh codends of flatfish and redfish. Paper submitted to Joint Scientific Meeting of ICES/ICNAF/FAO, 1957.

McKenzie, R. A. 1956. Atlantic cod tagging off the southern Canadian mainland. Bull., Fish. Res. Bd. Canada, No. 105, 93 pp.

McKenzie, R. A. and G. F. M. Smith, 1955. Atlantic cod populations along the Canadian mainland as shown by vertebral count studies. J. Fish. Res. Bd. Canada, 12(5):698-705.

McLellan, H. J. and L. Lauzier. 1956. The prediction of water temperatures. Canadian Fisherman, 43(9):11-12.

Paloheimo, J. E. 1957. Determination of natural and fishing mortalities; analysis of tag records off western Nova Scotia. Paper submitted to Joint Scientific Meeting of ICES/ICNAF/FAO, 1957.

Powles, P. M. 1957. Studies of feeding and reproduction of cod in southwestern Gulf of St. Lawrence. M.Sc. Thesis, University of Western Ontario, 1957.

Report of Ad Hoc Committee of the Permanent Commission. 1956.

Templeman, W. 1955. Groundfish stocks of the western North Atlantic. Trans., 20th N. Amer. Wildlife Conf., 1955, pp. 454-476.

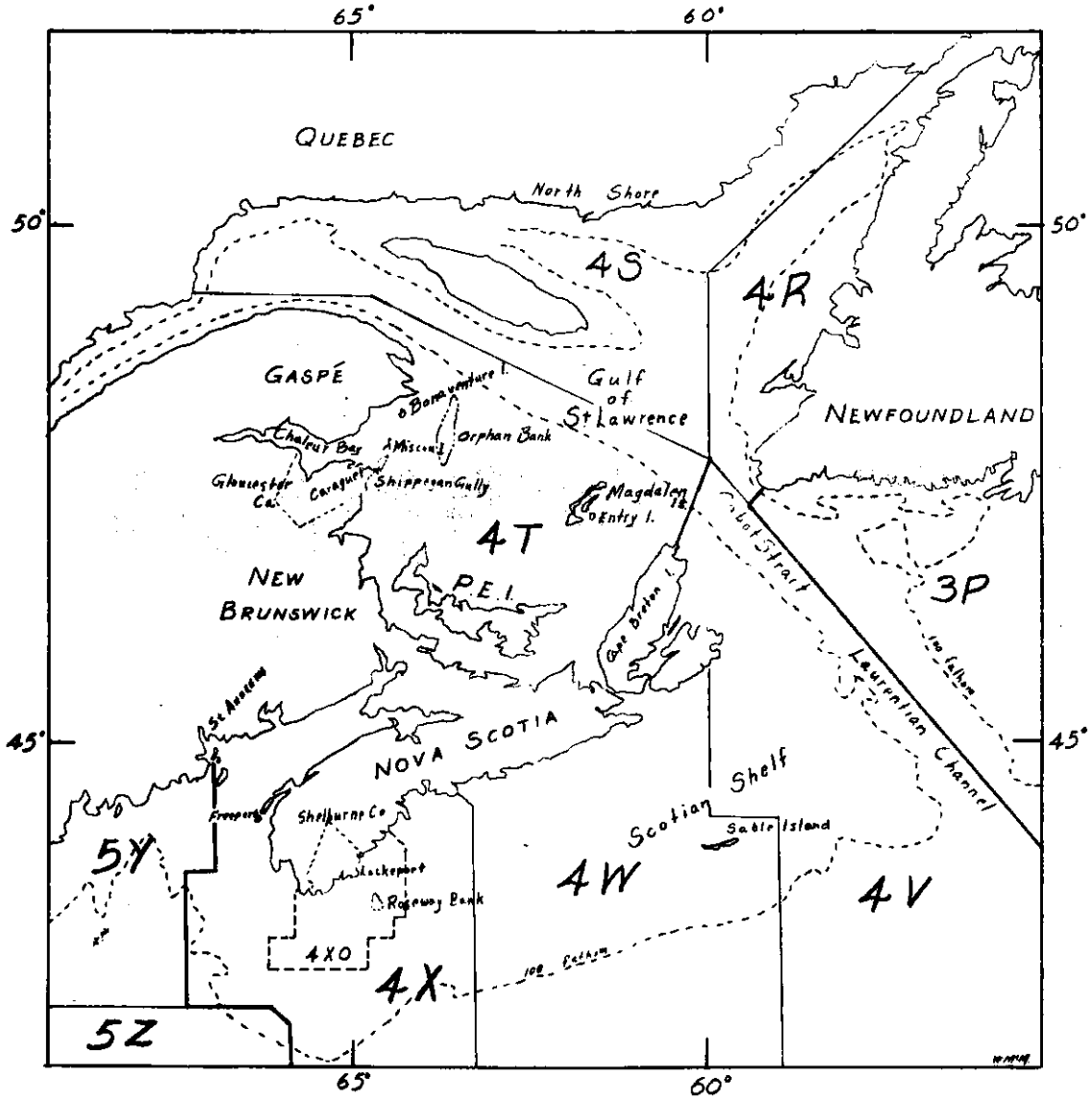

Figure 18. Map of subarea 4 showing geographic locations mentioned in text.